THE UNIVERSITY OF ALBERTA

AN OPTIMIZATION MODEL FOR WAFERBOARD PRODUCTION

by

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A THESIS

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ABSTRACT

A model, called **MAXPRESS**, was constructed for the constrained optimization of the press cycle of the waferboard production process. Two techniques were used in the optimization routine. The first technique, the Hooke-Jeeves Direct Search Algorithm, allows the optimization of non-differentiable, non-linear, discontinuous, or undefined functions. The second technique employed was Everett's method of Lagrange multipliers. This method transforms a constrained optimization problem into an unconstrained optimization problem, and thus allows the use of the Hooke-Jeeves Direct Search Algorithm.

MAXPRESS is a totally interactive program which prompts the user for all required input, and prints variable profit/shift and panel quality, as well as other parameters, at intermediate and final steps in the solution. Testing and evaluation indicated satisfactory model performance. Several recommendations are made for future research.

ABSTRACT

A model, called WASPREPS, was constructed for the computerized optimization of the grade cycle of the waferboard production process. Two techniques were used in the optimization routine. The first technique, the Hooke-Jeeves Direct Search algorithm, allows the optimization of nondifferentiable, non-linear, discontinuous, or undefined functions. The second technique employed was Everett's method of Lagrange multipliers. This method transforms a constrained optimization problem into an unconstrained optimization problem, and thus allows the use of the Hooke-Jeeves Direct Search Algorithm.

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GLOSSARY

fpm : feet per minute.

furnish : The wood particles from which waferboard is formed.

IB : Internal Bond; tensile strength perpendicular to the plane of the material; usually expressed in psi or Pa (pascal) (National Standard of Canada 1978).

MCF : Thousand (M) Cubic Feet.

MOE : Modulus Of Elasticity; the ratio of stress to strain, provided the stress does not exceed the elastic limit (and rupture the material); usually expressed in psi or Pa (pascal) (National Standard of Canada 1978).

MOR : Modulus Of Rupture; the maximum stress that a material can withstand before rupturing; usually expressed in psi or Pa (pascal) (National Standard of Canada 1978).

MSF : Thousand (M) Square Feet.

O.D. : Oven Dry; term used in association with weight; O.D. weight is determined by drying the specimen at a temperature of 105°C, until a constant weight is reached.

psi : pounds per square inch.

waferboard : A type of board product made predominantly from large wood 'wafers' (at least 30 mm. long), bonded together with a resin binder. Waferboard is a structural material and has been used extensively as a replacement for plywood.

3/8" equiv.: 'three eighths equivalent'; a base thickness for waferboard; most production figures are quoted in 3/8" equiv.

1. INTRODUCTION

This dissertation describes the development of an optimization model for the waferboard press cycle. This model is the most important component of a larger project to develop an optimization model for the entire waferboard production process[1]. The basic purpose for the development of a mill optimization model is to allow mill personnel to plan optimal management actions, especially in response to changes in the business environment, in a quick and inexpensive manner.

1.1 Model Scope

There appears to be three categories of questions which may be addressed with a waferboard production optimization model. The question(s) one wishes to address should determine the type of optimization model constructed. These questions deal with; 1) operating policy; 2) mill design; and 3) mill re-design.

1.1.1 Operating Policy Questions

The primary question affecting operating policy is how to achieve the most efficient operating policy with current mill equipment while meeting production and product quality objectives. Much of the equipment used in the manufacture of waferboard is highly specialized (and often custom built),

[1]Funding for this project was provided by the Forest Products Program of the Alberta Research Council.

and/or very expensive. Thus, the equipment set-up cannot be changed as readily as in some sawmilling situations (where there is typically a higher degree of equipment standardization and lower unit cost of equipment relative to waferboard manufacturing equipment). Therefore, a logical approach to the optimization of the waferboard production process over short time periods is to consider a current mill configuration as being fixed, and to establish the optimal operating policy for this configuration.

Given these assumptions, it becomes evident that the efficient operation of the press is essential to an efficient mill operating policy. The press is the most important, and most expensive, piece of equipment in a waferboard mill. Operating policy must be centered on the press, and the pressing cycle, because this is where the production variables (eg. moisture content and resin content of the furnish, press time, etc.) ultimately have an effect on the final product, in terms of both quality of product and rate of production. In this context, 'operating policy' refers to the selection of a set of values for the controllable production variables.

1.1.2 Mill Design Questions

The most important issue in this category is how to design a waferboard production facility so as to achieve a given level of production with optimal efficiency. Mill design questions are long term in nature, and very little

can be considered as 'fixed', unlike the operating policy questions where the existing mill configuration is fixed. Efficiency implies a relationship between both costs and benefits. Costs include the capital costs of the mill and related equipment, plus the capitalized expected costs of operating the mill over its life-span. Benefits include the capitalized expected revenues gained from operating the mill over the same time period. This problem could probably be reduced to one of 'line balancing', perhaps using queuing theory, with consideration being given to likely future operating policies. The optimal mill design would change with different operating policies. Thus, it is important to consider flexibility as a requirement to the mill design question. This would involve the identification of key production variables which are likely to change in either type, quantity, or cost (or some combination of these), and the quantification of their potential impact on operating policy.

Thus, it is clear that mill design questions are closely linked to operating policy questions. One must assume a mill design in order to establish an optimal operating policy. In the design of a mill, however, one must make assumptions about the likely (and, hopefully, optimal) operating policy which will be used.

1.1.3 Mill Re-Design Questions

Mill re-design questions link the first two categories described above. Here, one is investigating the possibility of re-designing portions of an existing mill to achieve a more efficient operating policy and a better mill design. Also, one is addressing questions of equipment replacement necessitated by the failure of existing equipment. The capital costs of the alternate investment opportunities (i.e. between different pieces of equipment) are weighed against the capitalized profits (revenues less expenses) resulting from the re-design.

1.2 Discussion

The original mandate of this project was to 'develop an optimization model for waferboard production'. Initially, the author sought to develop an overall mill model which would allow one to answer all three types of question outlined above. A survey of available literature revealed very little work in the area of waferboard (or particleboard) mill optimization models. In fact, only two sources, Harpole (1979) and Balmasoff (1975), were found which deal with this topic at all. The computer programs presented in both papers are econometric simulation (not optimization) models. They do not consider the physical flows of materials within a mill, and can only provide very general answers to mill operating policy questions.

Numerous models exist for the simulation or optimization of sawmills, or components of sawmills. Aune (1974) provides a good discussion of this type of mill model. Most such models utilize queuing theory to simulate the movement of logs and sawn lumber through the sawmill. These models determine the steady state conditions of the queuing system, and the user must resort to trial and error to test different mill configurations. This technique has some applicability for simulation of portions of the waferboard production process, where discrete individuals (such as logs or panels) move from station to station. It still does not address the problem of optimizating either operating policy or mill design.

A queuing model, coupled with an optimization routine, could be both feasible and practical for modelling some portions of the waferboard production process. Efforts were devoted to implementing an existing program (called DSMIN), developed by Carino and Bowyer (1979, 1981). DSMIN is a program designed for the optimization of some sawmill systems which can be represented by queuing models. The chief function of DSMIN is the optimization of mill design and re-design, with some application to the operating policy of sawmills.

Soon after establishing DSMIN on the University of Alberta computer, it became apparent that it would be useful only for the simple queues of a waferboard production process. Queues which have batch arrivals (this is the case

when the press is loaded and unloaded), cannnot be accomodated with this program. More important, it became evident that neither DSMIN, or any other queuing model, could enable one to properly model the complex operating policy questions encountered in the waferboard production process. Unlike sawmilling systems, the waferboard process involves numerous, and complicated, management decisions about production variables which are related indirectly to throughput of individual pieces of equipment. These production variables include moisture content of the furnish, the amount of resin applied to the furnish, panel density, wafer dimensions, press time, etc. (see **Decision Variables - The Press Cycle** in Chapter 3).

It was then decided that the first stage in the construction of the overall waferboard production optimization model should be the development of a sub-model. The sub-model should adequately deal with the operating policy questions. Eventually it could be linked with a queuing model such as DSMIN (but able to handle batch transfers as well), to answer all three categories of question about the entire mill.

Operating policy questions must be adequately answered before one can properly deal with mill design and re-design. Operating policy greatly affects the throughput of mill equipment which subsequently has a large impact on the latter two categories of question. In addition, for existing mills, it seems that operating policy is more important than

mill re-design. Much of the equipment in a waferboard mill is very expensive (often custom built), and cannot, therefore, be easily replaced or modified to achieve optimal throughput.

It soon became apparent that the press cycle should be the focus for this stage of the waferboard production optimization model. It is in the press cycle that all of the production variables come into play to affect both the quality of the panel product, and the output of the mill (through their effects on press time). This dissertation describes the development of a model which optimizes the press cycle and, hence, the principle components of the operating policy of a waferboard mill.

The next section of this dissertation contains a discussion intended to provide the reader with a basic understanding of the waferboard production process and the waferboard press cycle. After this, the two principle mathematical tools used to develop the model are discussed. These are the Hooke-Jeeves Direct Search Algorithm and Everett's method of Lagrange multipliers. This is followed by a complete discussion of the model, including a model user's guide, and an evaluation of model performance. A concluding chapter includes both general statements about the performance of the model and suggestions for additional research.

2. THE WAFERBOARD PRODUCTION PROCESS

This discussion, and schematic diagram (**APPENDIX I**), are included to provide the reader with a basic understanding of the waferboard production process. The Weldwood (of Canada) Ltd. waferboard mill, situated near Slave Lake, Alberta, is used as an example of a typical waferboard mill. Elements of the production process at the Weldwood mill are described in the order of the production flow, from the woodyard, where green aspen logs are stored, through to the end product warehouse. The mill complex has been divided into three sections for this discussion; 1) Harvesting and Woodyard; 2) Green Building, and; 3) Dry Building. Special reference shall be given to features of the production process which could have a direct bearing on production modelling efforts.

2.1 Harvesting and Woodyard

Weldwood hires logging contractors to harvest the aspen (*Populus tremuloides*) feedstock for the mill. Harvesting is conducted by the 'shortwood' method whereby whole trees are felled, skidded to a landing, and there bucked into 103" long logs. The logs are transported by truck to the woodyard adjacent to the mill, where they are unloaded. Wood in the yard is rotated on a 'First In - First Out' basis.

The woodyard is a large reservoir of material for the mill. From a modelling perspective, this reservoir can be

viewed as an infinite supply of discrete individuals.

2.2 Green Building

The Weldwood mill is divided into two main buildings. The 'green building' (the wood has not been dried, hence, 'green') houses that portion of the production process from log thawing and debarking, through to wafer drying. The 'dry building' (the wood has been dried, hence, 'dry') houses that portion of the production process from dry storage to actual panel formation and warehousing.

Logs are delivered in small bunches to the green building by a grapple loader. The logs are deposited into one of three log ponds. These log ponds are constructed of reinforced concrete, and serve principally to thaw the wood in the winter, and to clean the wood during all seasons. Logs are forwarded down the length of the ponds by forwarding chains, and arrive at the green building entrance individually from each log pond. Logs from all three ponds may enter the building at the same time, however, they are transferred to a single conveyor and are forwarded to the debarker as a single queue.

Logs are then fed through a rotating ring debarker, one at a time, where most bark is removed. Feed rate through the debarker can be varied, depending on the condition of the logs and bark (eg. how large the logs are, degree of thawing, etc.).

The next stage is the slasher deck. Logs are fed broadside, one at a time, into this set of circular blades and are cut into four 25" bolts. These bolts are then forwarded to the waferizers.

Three disc waferizers are used at the Weldwood mill. Normal operation has two units up, one unit down for maintenance (blade change, etc.). The waferizers accept bolts from the slasher deck, and feed them broadside into the knives on the rotating discs. Each waferizer has its own input queue of bolts which is fed from the single queue coming out of the slasher deck. Feed rate into the waferizers varies depending on the desired wafer thickness; the thicker the wafer, the faster the feed rate. Output from the waferizers is in the form of a flow of wafers.

The flow of wafers then passes through one of two rotating drum type 'green' screens, which separate the green 'fines' (small particles unsuitable for the manufacture of waferboard) from the green wafers.

The flow of green wafers then passes to one of three green storage bins which feed the wafer dryers. These bins provide a buffer for the production process. From the green storage bins, the wafers flow continuously into three natural gas-fired dryers, and then flow out of the green building. The time wafers spend in the dryers depends on the moisture content of the green wafers, the desired moisture content of the dry wafers, and the temperature in the dryers. The dryers at the Weldwood mill are each rated at

7000 O.D. pounds of wafers/hour.

2.3 Dry Building

The flow of dry wafers passes out of the green building into the dry storage bin of the dry building. The dry storage bin provides another buffer to the production process. Wafers pass through the dry storage bin on approximately a First In - First Out basis. After leaving the dry storage bin, the flow of wafers is separated, on the basis of wafer size, by a screen and vacuum pick-up, into two different flows. Each flow then passes through one of two rotating drum type dry screens (same function as the green screens). Large wafers (for the faces of the waferboard panels; comprising approximately 40% of the total) are fed through one screen, while small wafers (for the core of the waferboard panels; comprising approximately 60% of the total) are fed through the other.

Following screening, the two types of wafer pass into two surge bins, one bin for each type of wafer. Each surge bin mixes the flow of wafers passing through it, in order to achieve uniform bulk density. The two flows then pass into two rotary drum blenders where wax and phenolic resin are applied to the face and core wafers. The wafer flows then enter the press line.

The first components in the press line are the forming heads. Wafers flow into four forming heads; two for the face

of the panel, and two for the core. Cauls (steel sheets; approximately 16'x4'), overlapping at their ends, pass under the forming heads where wafers are dropped to form a continuous mat with random wafer alignment. Caul speed, and the rate of wafer flow onto the cauls, vary with different mat thicknesses for the production of different panel thicknesses. Cauls exit from the forming heads and are separated from each other.

A new queue is formed at the next stage, the 24-opening press loader, where cauls, with their wafer mats, are individually entered until all 24 positions are filled. The entire batch of cauls is then simultaneously transferred to the 24-opening press. The wafer mats are then pressed under high temperature and pressure (approximately 400°F. and 800 psi). Press time (usually ranging from 3 to 7 minutes) can vary depending on a number of parameters including panel quality desired, panel thickness, moisture content of the mat, etc. All 24 cauls are then unloaded simultaneously from the press to the 24-opening press unloader. From there, each caul is unloaded individually and separated from the pressed wafer mat. The pressed mats are rotated through a board cooler, and then pass through two sets of trim saws. The resulting 4'x8' panels are graded, bundled, and stored or shipped.

2.4 Discussion

The overall waferboard production process can be represented by a system of queues and flows (**APPENDIX I**). Queues consisting of logs exist at the debarker (single server) and the slasher deck (single server) while several (one, two or three) queues, made up of bolts, occur at the waferizers (multiple servers). A flow of wafers occurs from the waferizers to the forming heads. At the forming heads, another queue is formed, the elements of which are cauls. The cauls arrive at the press loader, and leave the press unloader individually, but are loaded and unloaded from the press in batches of 24. After being separated from the cauls, the pressed mats form queues at the panel cooler and at the trim saws. Grading and sorting could be viewed as part of the trim saw operation or as a separate queue. Panels are moved to the warehouse in batches.

3. THE MATHEMATICAL MODEL

3.1 Assumptions

The following basic assumptions have been made when formulating the mathematical model:

1. The overall goal for the waferboard mill is to maximize profits.
2. The mill must meet, or exceed, a single minimum level of quality for its waferboard production. In other words, there is no option for the production of a variety of panel grades which can then be sold for different prices. However, a variation of the standard application of the model can accomodate the case of varying panel qualities (refer to **Economic Significance of the Lagrange Multiplier** in Chapter 5).
3. All of the waferboard produced which meets the minimum quality level can be sold at a specified factory gate price (this price is provided by the model user).

3.2 Decision Variables - The Press Cycle

Numerous variables in the waferboard production process affect final panel properties and mill revenues and costs directly, and through interactions with each other. These variables include resin amount, type and distribution among layers of the wafer mat, moisture level and distribution in the wafer mat, panel density, press time, temperature,

pressure and rate of closure, particle geometry and orientation (if any), wood species, special additives, etc. (Maloney 1977). Many of these variables may be controlled, and could be considered decision variables for an optimization of the waferboard production process. In addition, these variables ultimately have their effect on both board quality, and mill production rate, when the wafer mat is pressed. Therefore, it becomes apparent that the press cycle is the most important part of the waferboard production process. Not only are final panel properties determined here, but in addition, press time will determine mill production rate and hence, revenue.

Four controllable production variables were selected as decision variables for inclusion into the mathematical model developed for this study. Operating policy is defined by a set of values for these four variables;

1. resin content of the wafer mat,
2. press time,
3. moisture content of the wafer mat,
4. nominal panel density.

These variables were selected because of their importance to panel quality and mill profits, and because data concerning their effects was available in the literature (refer to **Constraint Data Variable** in Chapter 6). It is important to note that other variables could, and probably should, be included into this model if sufficient data were obtained. The list of variables presented above is

by no means exhaustive, nor are the variables included necessarily the most significant ones in the waferboard production process. They do, however, illustrate model functioning very well.

3.2.1 Resin Content

As resin content in the wafer mat increases, all strength properties increase (Kelly 1977, Maloney 1977). In general, however, these strength properties increase at a decreasing rate.

Resin accounts for a major part of total mill expenses. The selection of optimal resin content, therefore, is very important to mill profitability. A mill optimization model should be constructed to allow the selection of the optimal resin content in response to resin price changes. Furthermore, most resins currently in use are synthetic in nature (produced from petroleum). It appears that resin prices will be closely associated with oil prices and could be subject to significant price increases in the future, as they have in the past (Maloney 1977).

Many different types of resin are currently available. Each has its own physical properties (for example, curing time) and cost. In addition, as synthetic resin costs rise, more work is devoted to the development of new resins which can be manufactured from natural products (Maloney 1977, Dolenko and Shields 1980). Because each resin has its own properties, a resin which is cheaper to purchase may not

necessarily be cost efficient. Such a resin could require longer press times for proper adhesion. This might result in a greater cost (through lost production) than the benefit gained through the lower resin prices. It is important to be able to properly evaluate new, or different, resins with a mill optimization model.

3.2.2 Press Time

Press time affects the rate of mill production (hence, mill profits) and final panel quality. In general, the core temperature of the wafer mat must reach the level required to cause the resin to cure, without subjecting the panel surface to excessive temperatures which result in degradation (Kelly 1977).

In the actual operation of a waferboard mill, there appears to be a relatively direct trade-off potential between resin content and press time (James 1981). Within limits, press time can be reduced if resin content is increased. Both panel quality and mill profits will be greatly affected by this trade-off. This is an important operating policy decision which is faced continually by mill managers. A mill optimization model should be capable of addressing this problem.

3.2.3 Moisture Content

Moisture content of the wafer mat directly affects heat transfer to the core and, therefore, is a critical factor for both press time (therefore, mill profits, as above) and panel quality (Kelly 1977, Maloney 1977). Surface moisture evaporates and travels to the core when the mat is pressed, thus allowing quicker heat transfer than would otherwise be possible (Kelly 1977). However, excessive moisture requires increased press time to allow for adequate evaporation through the panel edges, and to compensate for any adverse effects the moisture may have on resin curing (Kelly 1977).

Moisture decreases the compressive strength of wood and helps create a high density gradient in the finished panel product; the core tends to have lower density compared to the panel faces (Kelly 1977, Maloney 1977). This results in high bending strength parallel to the board surface (eg. modulus of rupture - MOR, and modulus of elasticity - MOE), and low tensile strength perpendicular to the plane of the panel (eg. internal bond - IB).

The level of moisture content in the furnish is directly related to fuel consumption in the gas driers, which is another component of total mill expenses.

3.2.4 Nominal Panel Density

Panel density depends on the amount and species of wood used, resin, moisture, and additives content, and pressing methods (Kelly 1977, Maloney 1977). In general, strength properties will increase as panel density increases, provided press time is adequate (Kelly 1977, Udvardy 1979).

Nominal panel density was included as a decision variable for this project because the Weldwood mill at Slave Lake uses 'stops' in its pressing routine. With the use of stops, variation of panel density is primarily a function of the mass of furnish in the wafer mat. This variable might be re-defined better as the mass of furnish on each caul entering the press. In any case, this variable helps illustrate the use of the optimization model.

Panel density also has a direct effect on the costs of production. As more furnish is added to the wafer mat to increase panel density, wood costs/panel increase, as do resin costs, fuel costs, etc.

3.3 The Optimization Model

With the removal of marketing considerations, as assumed in Section 3.1, the basic problem addressed by this study is the optimization of a payoff subject to a resource constraint. In particular, for the waferboard press cycle, the problem has been defined as the maximization of profit while meeting a minimum level of panel quality:

MAXIMIZE:

PROFIT = REVENUES - EXPENSES

SUBJECT TO:

QUALITY $\geq$ MINIMUM QUALITY

WHERE:

PROFIT = f_1{Resin Content, Moisture Content, Press Time, Panel Density}

QUALITY = f_2{Resin Content, Moisture Content, Press Time, Panel Density}

In the model, profit is measured in dollars/8-hour shift. Panel quality is measured as internal bond in psi. Other measurements of panel quality could be used (eg. MOR or MOE) instead of, or in addition to, internal bond (refer to **CONCLUSION AND RECOMMENDATIONS** in Chapter 9).

If assumptions, such as linearity, continuity, or differentiability, could be made about the objective function (f_1) and the constraint function (f_2), then classical optimization techniques such as linear programming, or differential calculus, could be employed to solve the constrained optimization problem. However, these assumptions cannot be made about f_1 or f_2 since almost nothing can be guaranteed about the nature of either relationship. In fact, the two relationships may not even be defined as functions (see **Design Considerations** in Chapter 6). The methods employed to solve the constrained optimization problem must therefore be capable of accepting the objective and constraint relationships in either

functional form, or as matrices of data.

These characteristics led to the selection of two relatively non-classical optimization techniques, the Hooke-Jeeves Direct Search Algorithm, and Everett's method of Lagrange multipliers, to accomplish the constrained optimization. Everett's method of Lagrange multipliers transforms the original, constrained optimization problem into an unconstrained problem. The optimal solution of the unconstrained Lagrange problem can then be found using the Hooke-Jeeves Direct Search Algorithm, without assumptions about the nature of the functional relationship. The Hooke-Jeeves Direct Search Algorithm is described in Chapter 4 of this dissertation. Chapter 5 contains a discussion of Everett's Method of Lagrange Multipliers. Details of the computer version of the model are then discussed in Chapter 6.

4. HOOKE-JEEVES DIRECT SEARCH ALGORITHM

The Hooke-Jeeves Direct Search Algorithm is a routine (called the 'pattern search routine') for optimizing (minimizing or maximizing) an unconstrained function S(ø) of one or more variables $ø=(ø_1, ø_2, ø_3, \ldots ø_n)$ (Hooke and Jeeves 1961).

The values of ø can be interpreted as points in *N*-dimensional space. A 'move' may be thought of as a vector projection in this space and is defined as the procedure of going from a given point (representing a particular value of S(ø)) to another point in the same *N*-dimensional space. A move is termed a 'success' if the value of S(ø) is improved (i.e. if S(ø) decreases in a minimization problem or increases in a maximization problem). A move is termed a 'failure' otherwise (Hooke and Jeeves 1961). The pattern search routine makes two types of moves; 1) exploratory moves; and 2) pattern moves.

4.1 Exploratory Moves

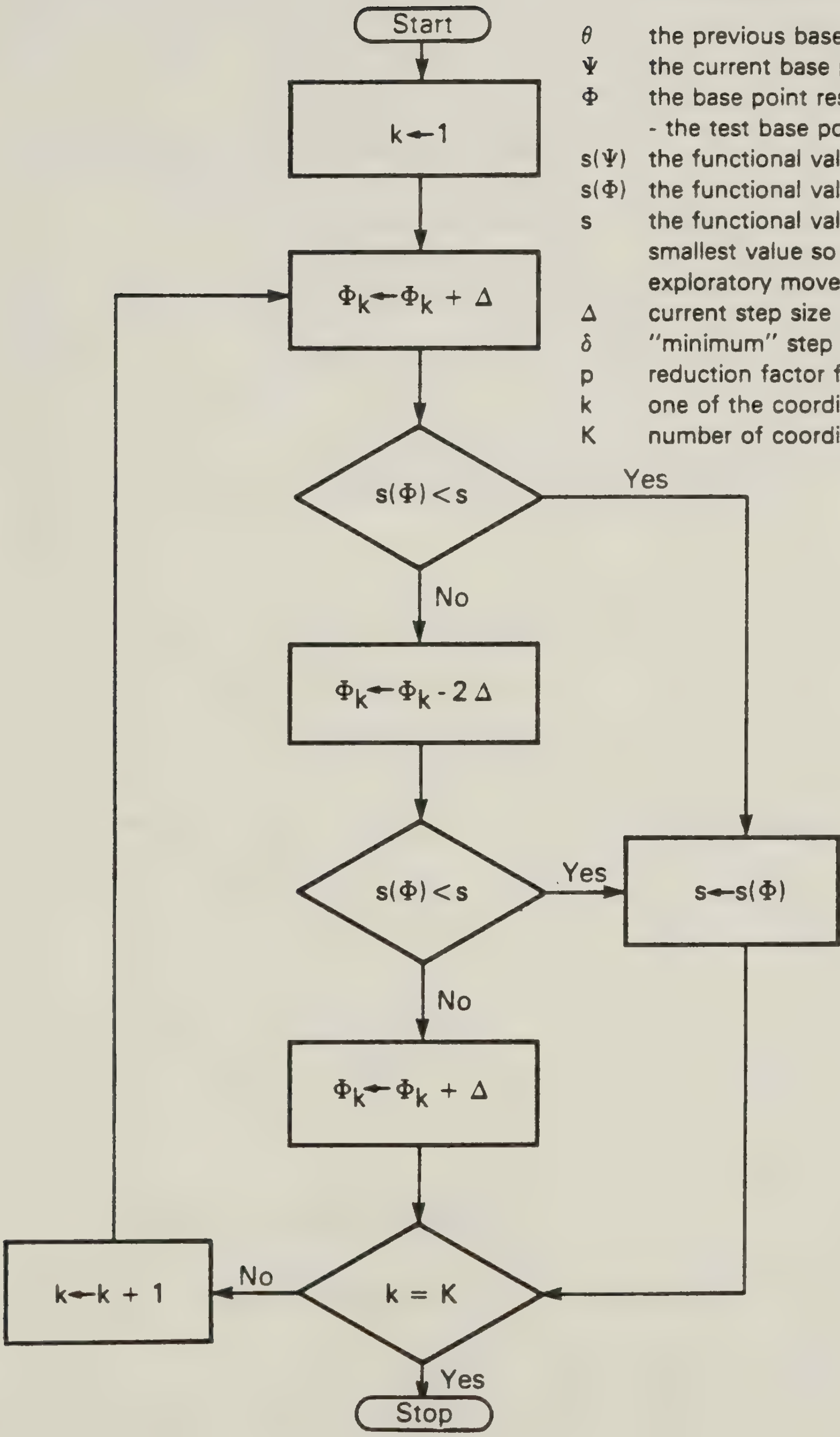
Exploratory moves acquire information about the behaviour of the function S(ø) solely by their success or failure (Hooke and Jeeves 1961). This information is utilized to establish a probable direction for a successful pattern move. Exploratory moves are achieved by changing the coordinate values (ø), one at a time, and comparing the new value of S(ø) to its previous value. Each coordinate (ø) is

first raised by some arbitrarily chosen step size, and S(ø) is evaluated. If the move is a failure, the original coordinate (ø) is lowered by the same step size and S(ø) is re-evaluated. Each time a successful move is achieved, the original set of coordinate values is re-set to include the coordinate value (ø) by which the successful move was achieved. The routine then moves on to the next coordinate. This procedure is carried out sequentially for all $ø_i$ (i=1,2,3 ... N) (Figure 1) (Hooke and Jeeves 1961).

4.2 Pattern Moves

Pattern moves are designed to utilize the information acquired by the exploratory moves about the behaviour of the function S(ø). A base point is defined as a point (represented by some particular set of coordinate values $ø_i$ (i=1,2,3 ... N)) from which a pattern move is made. Thus, pattern moves may be viewed as proceeding from base point to base point, with the pattern move from a given base point duplicating the combined moves from the previous base point (Hooke and Jeeves 1961). This is accomplished by changing all coordinates ($ø_i$ (i=1,2,3 ... N)) by an amount equal to the difference between the present base point, and the previous basepoint (Hooke and Jeeves 1961). As a result, once a pattern is established, the size of the pattern moves will increase, resulting in an acceleration in that direction (Phillips et al. 1976, Hooke and Jeeves 1961).

Figure 1. Flow Diagram for Exploratory Moves of Pattern Search Routine



Legend

The variables Ψ, θ and Φ are points in a K-dimensional space; the rest of the variables are unidimensional.

θ	the previous base point
Ψ	the current base point
Φ	the base point resulting from the current move - the test base point
$s(\Psi)$	the functional value at the base point
$s(\Phi)$	the functional value for this move
s	the functional value before this move (usually, the smallest value so far attained by the set of exploratory moves)
Δ	current step size
δ	"minimum" step size
p	reduction factor for step size, $\rho < 1$
k	one of the coordinate values for Φ, $k = 1,2,\ldots,K$
K	number of coordinates for the points

The argument for pattern moves is intuitive in nature; if a set of moves was successful in the past, it is likely to be successful again in the future (Hooke and Jeeves 1961). The pattern move procedure is clarified by the following discussion of the overall pattern search routine.

4.3 Pattern Search Routine

A detailed flow diagram of the pattern search routine is shown in Figure 2 and its graphical analogy is shown in Figure 3. Using function minimization for illustrative purposes, the following steps are performed in the pattern search routine (Hooke and Jeeves 1961):

STEP 1.

- Start at the 'current base point' (arbitrarily chosen for initial iteration).
- Make exploratory moves. The base point resulting from these moves is the 'test base point'.
- Is the functional value at the test base point below that at the current base point?
- YES: Go to STEP 2.
- NO : Go to STEP 3.

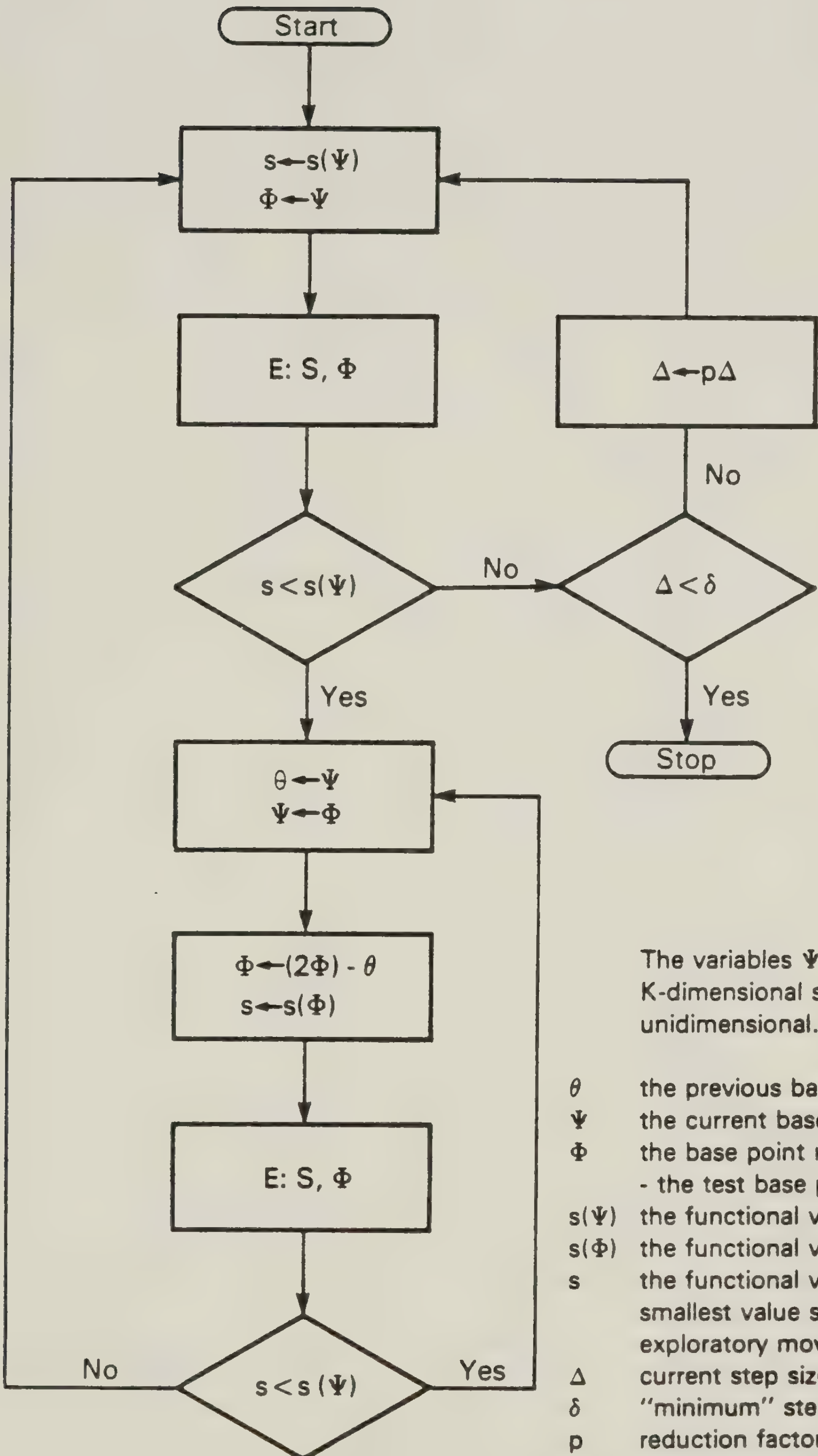
STEP 2.

- Re-set base points;

  'current base point' becomes 'previous base point';

  'test base point' becomes 'current base point'.
- Make pattern move by doubling the coordinates of the

Figure 2. Flow Diagram for Pattern Search Routine



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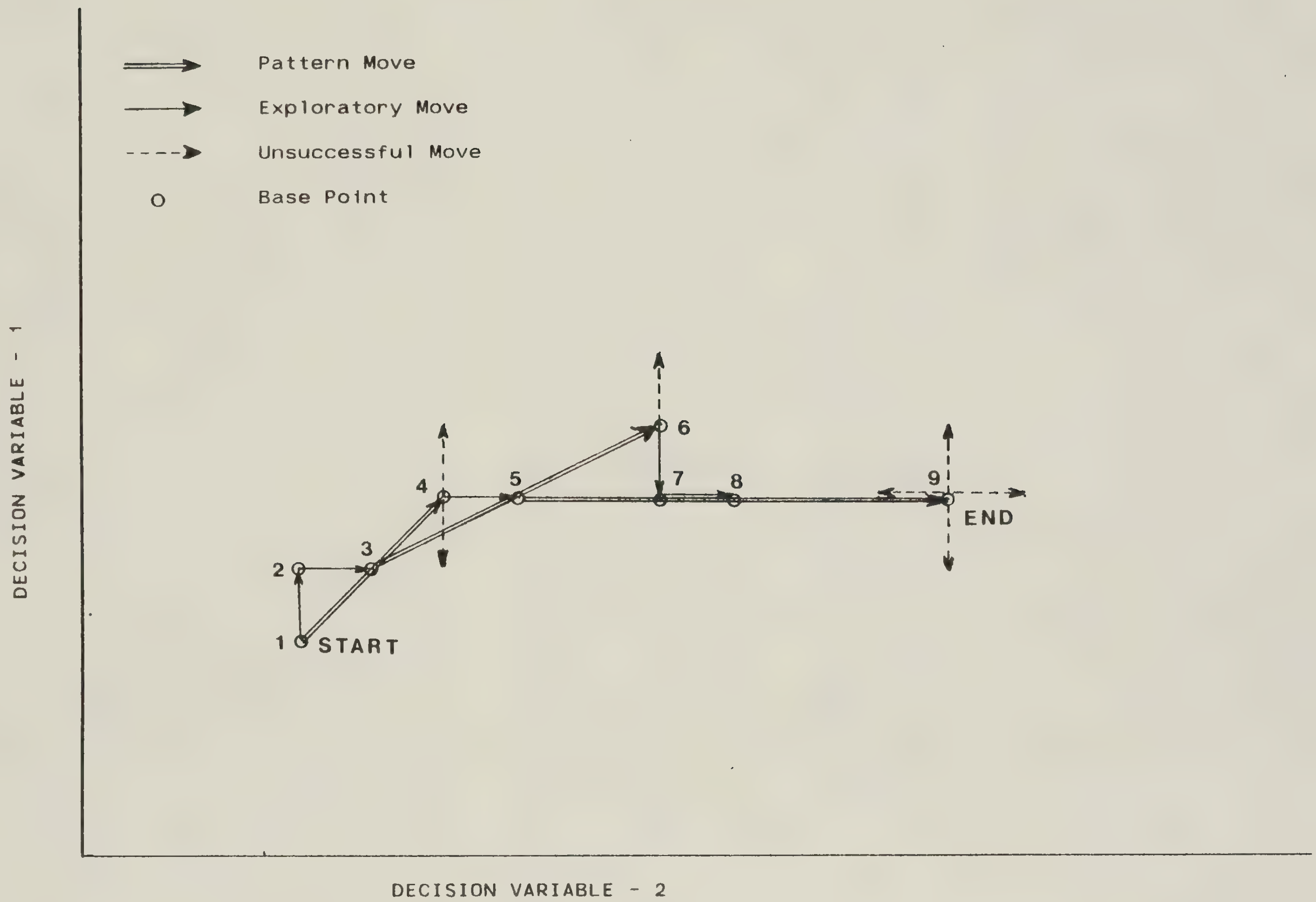
Δ	current step size
δ	"minimum" step size
p	reduction factor for step size, $\rho < 1$
k	one of the coordinate values for Φ, k = 1,2,...,K
K	number of coordinates for the points
E	exploratory search routine

Figure 3. Graphical Analogy of Pattern Search Routine



test base point (now the same as the current base point), and subtracting the coordinates of the previous base point. This is the test base point.

- Make exploratory moves. The coordinates of the test base point may, or may not, be changed by these moves.

- Is the functional value at the test base point below that at the current base point?

- YES: Go to STEP 2.

- NO : Go to STEP 1.

STEP 3.

- Is step size for exploratory moves small enough (compared to an arbitrarily chosen minimum) ?

- YES: STOP.

- NO : Decrease step size; Go to STEP 1.

Hooke and Jeeves (1961) suggest that all pattern moves be immediately followed by exploratory moves (STEP 2), before testing the pattern move for success. Their rationale is as follows:

Because more progress towards optimizing the function S(ø) is made with pattern moves than with exploratory moves, it is desirable to retain pattern moves where possible. A pattern move which otherwise would have failed can sometimes succeed and, hence, be retained, if exploratory moves are made after the pattern move and this result tested for success. Thus, the success or failure of a pattern move becomes irrelevant to the mechanics of the routine because in either case, exploratory moves are made immediately

following the pattern move. This strategy is most likely to succeed when the pattern is first being established (Hooke and Jeeves 1961).

4.4 Discussion

There are several practical considerations to the Hooke-Jeeves Direct Search Algorithm which affect potential applications and are, therefore, discussed here.

A primary advantage to using the Hooke-Jeeves Direct Search Algorithm is that the objective function to be optimized does not have to be regular, continuous, or differentiable, nor does it have to be explicitly defined (Carino and Bowyer 1979, Phillips et al. 1976, Hooke and Jeeves 1961). This is a particularly useful feature for applications such as the waferboard production model presented in this thesis. In this case, the objective function is a combination of an explicitly defined profit function and a constraint relationship represented by discrete data in a tabular format. In addition, the algorithm lends itself well to use on computers, since it uses repeated arithmetic operations with simple logic (Hooke and Jeeves 1961).

A disadvantage to the Hooke-Jeeves Direct Search Algorithm is that the global optimum will not always be found. With some objective functions (ie. those defining a non-convex feasible region) it is possible, even probable,

that some of the solutions produced by this algorithm will be local optima only. In such cases, it appears that the only practical solution is to start the search from several arbitrarily chosen points and compare the resulting solutions. This will not, however, guarantee finding the global optimum. It only increases the chances of such an occurrence.

5. EVERETT'S METHOD OF LAGRANGE MULTIPLIERS

Everett's method of Lagrange multipliers is useful for optimization subject to constraints, especially in problems where discontinuous or non-differentiable functions must be optimized (Everett 1963). This property of Everett's method is particularly useful to some applications, such as the waferboard production model described in this dissertation, where little is known about the nature of either the function to be optimized or the constraints which limit possible solutions (eg. functional form, linearity, etc.). Clearly more conventional techniques for constrained optimization, such as linear programming, could not be used in this situation.

The following discussion of Everett's method of Lagrange multipliers will deal primarily with the practical applications and problems associated with this technique. However, some discussion of the theoretical justification for Everett's method is warranted, and follows in the next section.

5.1 Main Theorem

Using the terminology of Everett (1963) the main theorem shall be discussed in terms of the optimal allocation of limited resources. In other words, the problem is the maximization of a payoff function subject to given constraints. The waferboard production process provides a

good example. In this process the objective is to maximize profits, subject to quality constraints on the waferboard panel product. Quality may be measured by internal bond (IB), modulus of rupture (MOR), modulus of elasticity (MOE), etc.

5.1.1 Definitions

The following definitions are used in the discussion of the main theorem, and are derived from Everett (1963) with one major change; only one resource function and constraint is considered[2]:

1. x: The decision variables (i.e. resin content, press time, moisture content, panel density).
2. S: The set of possible strategies. (eg. the possible combinations of the decision variables to produce waferboard of various quality levels, at various production rates).
3. H: A real valued function called the 'payoff function' .
4. H(x): The payoff which occurs as a result of employing the strategy $x \epsilon S$ (eg. could be expressed as profit/8-hour shift).
5. C: A real valued function called the 'resource function'.
6. C(x): The resource expenditure (panel quality is the resource considered in the waferboard press cycle) required to gain payoff; occurs as a result of employing

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[2] The waferboard production model allows for only one constraint (internal bond); see **Constraint Data Variable.**

the strategy $x \epsilon S$. In other words, some resource must be given up in order to gain payoff. This could be thought of as an 'expenditure' or 'loss' of quality (eg. measured by internal bond) in the waferboard panels in order to achieve more profit.

7. c: The maximum resource expenditure allowed.

5.1.2 Discussion

The problem then becomes:

MAXIMIZE:

$$H(x) \text{ over all } (x \epsilon S)$$

SUBJECT TO:

$$C(x) \leq c$$

The main theorem follows (for a proof of the main theorem, see Everett (1963)):

1. λ is a nonnegative real number,
2. $x^{+} \epsilon S$ maximizes the function,

$$H(x)-\lambda C(x) \text{ over all } x \epsilon S,$$

3. x^{+} maximizes $H(x)$ over all those $x \epsilon S$ such that $C \leq C(x^{+})$.

In other words, for any choice of nonnegative λ, if an unconstrained maximum of the Lagrange function (item 2, above), can be found (x^{+} is the strategy which produces this maximum), then this strategy will also produce the maximum of the constrained function with constraints equal to the amount of the resource expended in achieving the unconstrained solution (Everett 1963).

Using the main theorem, one can arbitrarily choose a non-negative λ and find the maximum of the unconstrained, Lagrange function. This solution will also provide the maximum of the original, constrained function, with constraints equal to the amount of resources expended in the unconstrained solution. It is important to realise, however, that the choice of λ is completely arbitrary, and different choices of λ will generally lead to different resource levels. If one is interested in maximizing a payoff function (such as gross revenue/8-hour shift) while not exceeding a given resource expenditure (eg. loss of internal bond below some minimum allowable level), it is likely that the value of λ will have to be adjusted by trial and error until the desired constraint level is achieved (Everett 1963).

5.2 Economic Significance of the Lagrange Multiplier

The Lagrange multiplier (λ) also provides some information about the cost of the constraint. By the Lambda Theorem (for a discussion and proof of this theorem, refer to Everett (1963)) it can be shown that at any optimal solution, λ represents the marginal value per unit of resource. In the waferboard production case, λ would represent the profit gained by the 'expenditure' of one additional unit of quality (eg. loss of one unit of internal bond). This feature could have implications for a mill's operating policy because as resource costs change, so does

the cost of achieving a given level of panel quality. In addition, if one has the option of marketing several different grades of product, it could prove optimal to vary the quality of the product in response to changes in resource prices and selling prices for the panel product. In other words, if the situation arose where a waferboard mill could actually make a higher profit by producing different quality panels, Everett's method of Lagrange multipliers could help to identify the optimal quality level of panel to produce.

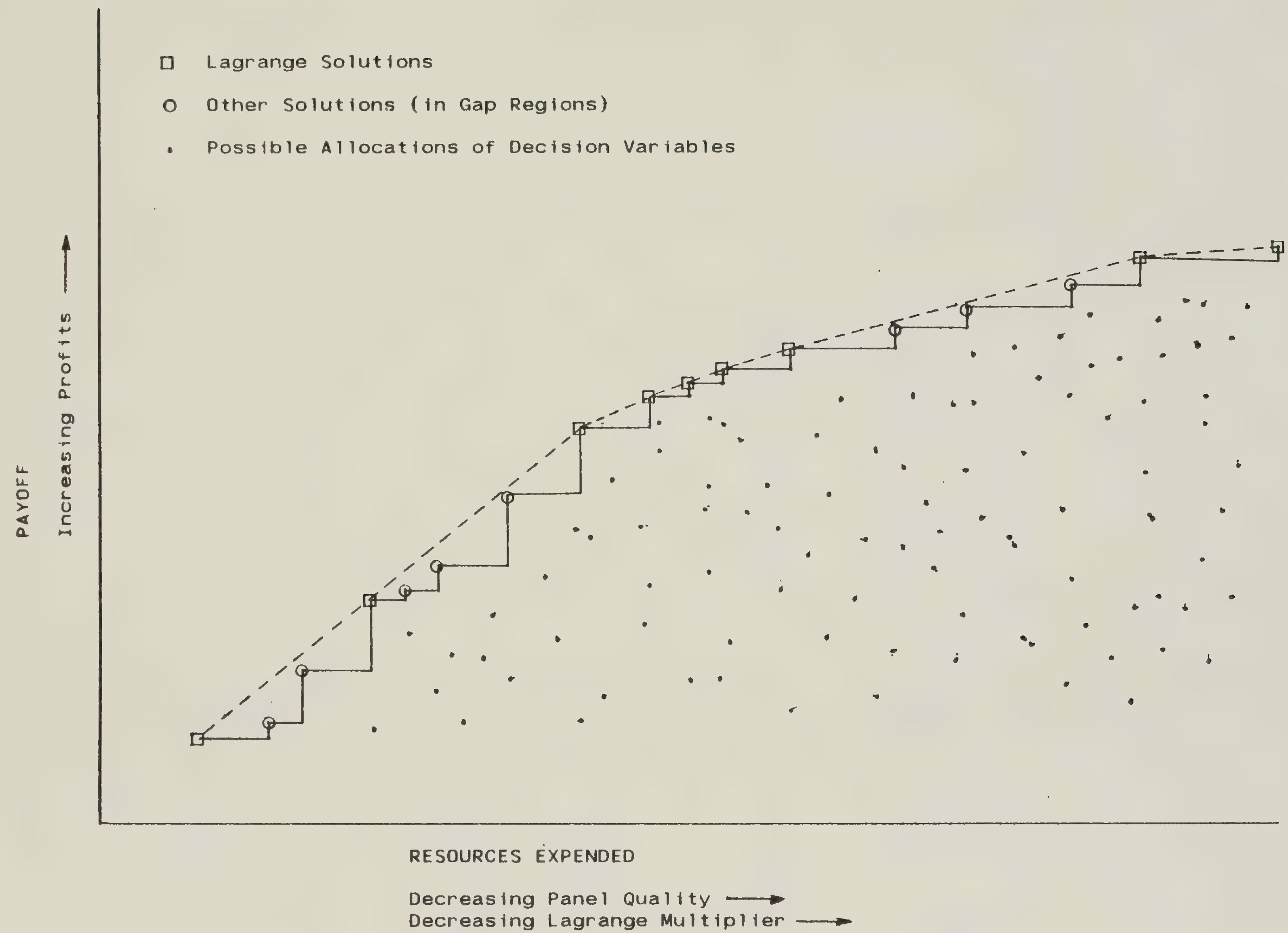
5.3 Gaps or Inaccessible Regions

The use of Lagrange multipliers does not ensure that a solution will necessarily be found for all problems, however, a solution found by their use is guaranteed to be a true solution (Everett 1963). There is no guarantee, however, that some constraint levels will not be generated by any values of λ. These are are termed inaccessible regions (also called 'gaps') (Everett 1963).

A gap can be recognized by abrupt dicontinuities in the resource levels generated as λ is continuously varied (i.e. for two levels of λ which are very close, the corresponding resource levels generated are considerably different).

The basic cause of gaps is nonconcavity in the function of optimum payoff versus resources expended (Figure 4) (Everett 1963). The Lagrange method will succeed in

Figure 4. Payoff vs. Resources Expended - An Illustration of Gaps



* Adapted from Everett (1963)

producing all solutions in the concave regions of this function, and will fail in all non-concave regions. Solutions in the inaccessible regions cannot be obtained by a simple application of the Lagrange multiplier method, and must be sought using different techniques (Everett 1963).

5.4 Method for Handling Gaps

Several methods for handling gaps are presented by Everett (1963), but only one of these methods, the most applicable to the waferboard production model, will be discussed here.

Consider the standard case where one is seeking to maximize some payoff function subject to constraints. If the decision variables are discrete (indeed, as will be explained later, they are discrete in the waferboard production model), then nearly optimal solutions can be produced by deliberately deviating slightly from the optimal combination of decision variables which last maximized the Lagrange function. This can be achieved by examining all possible combinations of the decision variables ± one step (or more) away from the last optimal combination (C) of the decision variables (i.e. the last combination which produced an optimum solution using the direct application of Everett's method). The Lagrange solutions are generated for all of these combinations, and are then subtracted from the Lagrange solution obtained with C. The resulting deviations,

with their corresponding combinations of decision variables, are then ordered from lowest to highest. A member of this ordering is 'dominated' if a preceding member provides more payoff for equal, or less, resource expenditure. Dominated members can then be dropped out of the ordering, since they are not optimal solutions. Remaining members of the ordering define acceptable strategies for the combination of decision variables. These are represented by corner points ('OTHER SOLUTIONS') in the non-concave regions of the optimum payoff vs. resources expended function of Figure 4. If a minimum constraint level must be achieved (such is the case in the waferboard press cycle, where minimum panel quality standards must be met), the undominated combination of decision variables which provides a constraint level closest to, and greater than, the minimum constraint level allowed can be selected. This will be the best possible solution because no other members of the ordering will provide the same, or more, payoff for equal, or less, resource expenditure. In other words, for the waferboard press cycle, the undominated member (combination of decision variables) of the ordering which provides a level of panel quality closest to, and greater than, the minimum specified level of panel quality, is selected. No other member of the ordering will provide the same, or more, panel quality (equivalent to the same, or less, expenditure of panel quality) with the same, or more, profit.

In some cases, such as the waferboard press cycle, where little is known about either the payoff or constraint relationships, one could guarantee that the best solution (i.e. undominated member of the ordering closest to the minimum quality level) is found only if all feasible combinations of the decision variables are examined. Obviously, this is not practical. In fact, this strategy would make the use of Everett's method of Lagrange multipliers obsolete, because all possible solutions would be generated directly. In this case, justification for examining combinations of decision variables within a limited range of C is intuitive in nature, and is supported by empirical results. It seems logical, in most cases, to assume that solutions (i.e. combination of decision variables) occurring in gap regions will be close to the last known solution which bounds the gap. This assumption was tested, and found to be valid, for gaps produced by the objective and constraint relationships developed for this study. All possible combinations of decision variables were generated, and the best combination was selected for the resource level desired. For all cases tested, this result was the same as the result obtained using gap search techniques directly.

The same justification could be presented for the use of gap search techniques around an optimal solution obtained directly with Everett's method, but which is not necessarily at the edge of a gap. If a resource level generated with a

particular value of λ is close to the desired resource level, a direct application of gap search techniques could provide the optimal solution quicker, and easier, than further manipulation of λ. Once again, the only justification for this procedure is intuitive in nature, and supported by empirical results. Since the underlying aim of this project was to construct a useful, practical tool, it was felt that these gap search procedures should be available in the waferboard production model.

6. THE COMPUTER MODEL - MAXPRESS

The model developed for this dissertation has been named **MAXPRESS**[3], an optimization model for the press and pressing cycle of a typical waferboard production facility. **MAXPRESS** maximizes variable profit/8-hour shift while meeting minimum panel quality specifications (measured as internal bond in psi).

6.1 Design Considerations

MAXPRESS has been constructed with the following conditions and desired features in mind:

1. **MAXPRESS** should be able to accept non-differentiable, non-linear, and discontinuous objective (payoff) functions. The author felt that a payoff function could be defined, but that very little could be guaranteed about its properties. In addition, **MAXPRESS** should be constructed so that it could be easily modified to allow for the situation where the objective function could not be defined, and where the payoff information was provided in the form of discrete data for various combinations of decision variables.
2. **MAXPRESS** should accept constraint information in the form of discrete data for various combinations of decision variables. This condition was recommended by Dr. Lars

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[3] **MAX**imization of the **PRESS** cycle.

Bach[4] and was verified by an examination of waferboard quality relationships in the literature. Good functional relationships between waferboard quality (eg. internal bond) and production variables (eg. resin content, press time etc.) appear to be non-existent in the literature. This might be due to the complexity of the relationships involved. It does appear, however, that fairly good data can be obtained from the literature (certainly, any forest products company wishing to use a model such as **MAXPRESS** could provide this data) in the form of repeated measurements (or averages of such measurements) of quality for various combinations of decision variables. A major problem with such data obtained from the literature is the wide variety and incomplete description of testing methods used.

Furthermore, anomalies could occur in a particular waferboard mill which might significantly alter quality/decision variables relationships. In such a case, it is desirable to have a model which could use quality data from trial production runs, or from an 'educated guess' of mill personnel, without trying to develop predictive functions using techniques such as linear, or non-linear, regression.

3. **MAXPRESS** must be an optimization model, not a simulation model. The ultimate goal, and mandate, of this project

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[4] Program Manager, Forest Products Program, Alberta Research Council and member of the author's examination committee.

is to produce an optimization model for an entire waferboard production facility which can be used by mill personnel.

4. **MAXPRESS** should be easy to use. For example, waferboard production personnel at a mill (eg. the quality control manager) with no formal training in computer programming or operations research should be able to use the model to easily answer particular questions about the mill's operating policy.

6.2 Model Construction

MAXPRESS, the model constructed, meets all of the requirements described above. It is an optimization model designed to accept any type of explicitly defined objective (payoff) function, and quality relationships in the form of discrete, tabular data. Optimization is achieved by using the Hooke-Jeeves Direct Search Algorithm (pattern search routine) in combination with Everett's method of Lagrange multipliers. The pattern search routine was modified to allow discrete constraint inputs to the model. As a result, the step size for exploratory moves must equal the interval size of the constraint matrix, and no reduction in step size is allowed. No limiting assumptions are required for either the objective (payoff) function or the constraint (quality) data variable.

MAXPRESS is a totally interactive computer program which prompts the user for all required inputs, and automatically provides the required output. The model user does not require any special knowledge about computers or computer programming, other than how to access his own system. Some understanding of the role of the Lagrange multiplier (called LAMBDA in the model) is required (see **The Role of LAMBDA** in Chapter 7).

MAXPRESS was formulated in APL (A Programming Language, Gilman and Rose 1976). All major routines are composed of different subordinate functions which are called by a main function as required. This modular composition, characteristic of programs written in APL, permits easy substitution of various functions or the addition of new options. For example, a different profit function (eg. for a specific waferboard mill) could easily be incorporated into **MAXPRESS** simply by defining the new relationship in APL and then replacing the old function with this newly defined version. This inherent flexibility of APL was the primary reason for its selection as the computer language for the development of **MAXPRESS**.

6.3 Model Components

As mentioned previously, **MAXPRESS** is characterized by a modular composition. The main components, defined by their APL function or variable name, are described here. For a

complete, fully commented alphabetical listing of all APL functions in **MAXPRESS**, refer to APPENDIX II.

6.3.1 Main Routine

The principal component of **MAXPRESS** is a function named SEARCHMAX. This function performs the pattern search, prints intermediate and final output, and calls the other functions in **MAXPRESS**, as required. SEARCHMAX is called by the function START.

6.3.2 Gap Search Routine

GAPQ, a function called by SEARCHMAX, performs a gap search, if so desired. The user specifies the perturbation depth desired. This refers to the number of steps away from the last Lagrange solution that the user would like to consider (a maximum of three is allowed). For example, with a perturbation depth of one, the Gap Search Routine would examine all possible combinations of the decision variables (moisture content, resin content, panel density and press time) ± one step away from the base set of values specified by the user. The optimal value (i.e. not dominated; see **Method for Handling Gaps**) nearest to, and greater than, the minimum level of internal bond specified by the user is selected, and the appropriate output for this combination of variables is printed. The perturbation depth requested when the Gap Search Routine is invoked should depend on several parameters. In general, the smaller the gap, or the closer

the desired level of internal bond is to the last solution level of internal bond, the smaller the perturbation depth required to produce the optimal solution. In addition, the perturbation depth requested should depend on the size of the computer used. Memory requirements, and the cost of running the Gap Search Routine, increase rapidly with increasing perturbation depth. Ultimately, the selection of perturbation depth is subjective in nature and depends upon past experience of the user.

6.3.3 Objective Function

The objective function (OBJFCN) used in **MAXPRESS** computes the variable profit (dollars/8-hour shift) net of variable expenses. Fixed costs are not considered. These terms of reference are completely arbitrary. If desired, a user could easily re-define OBJFCN with different terms of reference. It should be noted, however, that a true fixed cost (i.e. one which must be borne regardless of the activity level of the waferboard mill) will not affect the solutions derived using **MAXPRESS**. To illustrate how a simple objective function can be constructed, the derivation of OBJFCN will be discussed.

Definitions:

1. TP = Total Profit,
2. VP = Variable Profit,
3. TC = Total Costs,
4. FC = Fixed Costs,

5. VC = Variable Costs,
6. TR = Total Revenue,
7. VR = Variable Revenue,
8. Q = Quantity produced; expressed as MSF/Shift,
9. t = time for one press load to be completed (minutes),
10. T = Time in one shift (minutes).

The two basic components required in the objective function are expressions for VR and VC. A suitable 'activity' base must be chosen for the allocation of these costs and revenues. Fluctuations in the activity base should be closely correlated to fluctuations in the variable costs and revenues. In OBJFCN, one MSF (thousand square feet; of whatever panel thickness one is interested in) was chosen for the activity base. Q must then be calculated (one could refine this calculation by allowing for down time; see **CONCLUSION AND RECOMMENDATIONS**):

Q (MSF/S) = T/t x 48 (Panels/Press Load) x 0.032 (MSF/Panel)

Once Q has been established, VC and VR must be calculated. VR/MSF is provided by the user, and is simply the selling price/MSF at the factory gate for a particular thickness of waferboard. VC/MSF is somewhat more difficult to calculate. Following are the different components of VC, together with the decision variables (resin content = RC, moisture content = MC, press time = PT, and panel density = DEN; see **Decision Variables - The Press Cycle**) which directly affect these costs:

1. Resin cost = f(RC, DEN),

2. Wax cost = f(DEN),

3. Wood cost = f(DEN),

4. Fuel cost (for drying wafers) = f(MC, DEN),

5. Other variable costs = f(overall mill activity)

   - labour,
   - waste (eg. panel trim, wafer fines, etc.),
   - variable overhead,
   - electricity,
   - other supplies,
   - miscellaneous.

The decision variables included in the optimization model interact with each other to affect VR and VC, both directly and indirectly. Press time is the only decision variable which directly affects VR, but changes in the other variables will indirectly have an effect through their impact on panel quality. The effect on panel quality could change the optimal level of press time, hence, this could also change VR. Similarly, resin content, moisture content, and panel density have a direct effect on VC, but press time can indirectly have an effect through its impact on panel quality, and subsequent changes in the optimal levels of the other decision variables.

In OBJFCN, only the first four items in the list, above, are treated explicitly, as they can be easily allocated to MSF. The remainder are lumped into a category called 'other variable costs'. Splitting this general category into smaller, more specific, categories could

result in a significant improvement of OBJFCN, if they could be allocated properly. VP can then be derived:

$$VP(\text{dollars/shift}) = Q \times \{VR - VC\}$$

If FC is known, TP can be calculated:

$$TP(\text{dollars/shift}) = VP - FC$$

6.3.4 Constraint Data Variable

The constraint data variable (CONMAT) used in **MAXPRESS** was derived from various sources in the literature. Internal bond was selected for use as the only quality constraint in **MAXPRESS**. Although several measures of quality could be used in the Lagrange optimization of the press cycle, a different value for LAMBDA would have to be selected for each, complicating the operation of the model considerably. In addition, from an operational viewpoint, it appears that internal bond is usually the limiting factor in waferboard production. Attainment of adequate MOR and MOE is usually much easier than reaching adequate levels of internal bond (James 1981).

The primary source for relationships between panel quality (internal bond) and production variables was Udvardy (1979) (for a graphical representation of this data, refer to **APPENDIX III**). The panels in this study had the following specifications:

- 7/16" aspen waferboard,
- "industry produced flakes",
- press temperature = 400°F.,

- moisture content = 6% of O.D. furnish,
- resin content = 2% and 2.5% of O.D. furnish (phenol formaldehyde resin),
- nominal panel density = 32, 40, and 48 pcf,
- press time = 3, 5, 7 minutes.

More data was sought, especially for different levels of production variables which were not varied here (eg. press temperature, moisture content, flake dimensions, etc.), but with little success. Difficulty was encountered due to a lack of published data and also to the wide variety of testing methods used by various researchers. A reasonable approximation for different levels of moisture content was obtained by averaging the results of several studies (Johns et al. 1981, Halligan and Schiewind 1971, Bryan and Schiewind 1971). The published data for the four resulting production variables (moisture content, resin content, panel density, and press time) were used as reference points through which relatively smooth curves were hand-fitted. Specific points (i.e. specific values for internal bond, measured in psi, for different combinations of the four decision variables) were then entered into a data variable for use with **MAXPRESS**. The resulting data variable has the following dimensions: 5 (levels of panel moisture content; from 6% to 8% on an O.D. basis) x 5 (levels of panel resin content; from 2% to 2.5% phenol formaldehyde resin) x 9 (levels of panel density; from 32 to 48 pcf) x 9 (levels of press time; from 3 to 7 minutes) = 2025 elements. These data

are only a rough approximation to what one might use in a real-world application of **MAXPRESS**, and are only intended to demonstrate the operation of the model. If better data were available (eg. from a waferboard production company), they should be incorporated into the model. In addition, more production variables could be added if the data were available.

7. MODEL USER'S GUIDE

7.1 Model Inputs

Two types of input are required to operate **MAXPRESS.** The first type of input must be prepared beforehand, and loaded into an APL workspace with **MAXPRESS.** This type of input is referred to as 'General Input'. The second type of input is provided by the user when **MAXPRESS** is run. This type of input is referred to as 'User Provided Input'.

7.1.1 General Input:

There are two major pieces of general input required to run **MAXPRESS**; 1) an objective function and; 2) a constraint relationship (in the form of discrete data). The objective function provides the payoff relationship for the particular mill in question, while the constraint data provides the quality relationship between decision variables (eg. press time, resin content etc.) and some measure of quality such as internal bond (see **Model Components** for a description of the standard objective function and constraint variable developed for **MAXPRESS**). The objective function is defined as an APL function (called 'OBJFCN'; see **APPENDIX II**), while the constraint data is stored in an APL data variable.

7.1.2 User Provided Input:

MAXPRESS prompts the user for the following cost and revenue inputs:

1. Panel thickness (inches; currently, the user can only use .4375" (7/16") due to a lack of data for panel quality relationships to production variables),
2. Resin cost (dollars/pound),
3. Wax cost (dollars/pound),
4. Wood cost (dollars/O.D. pound of wafers),
5. Fuel cost (dollars/MCF natural gas),
6. Other variable costs (dollars/MSF waferboard),
7. Selling price at the factory gate (dollars/MSF waferboard),

The minimum possible value, maximum possible value, and step size (for the Hooke-Jeeves Direct Search Algorithm - step size must equal the interval size of the constraint matrix), for each of the following variables:

8. Moisture content of the panel (% of O.D. panel weight),
9. Resin content of the panel (% of O.D. panel weight),
10. Panel density (pcf),
11. Press time (minutes),

The starting point for the Hooke-Jeeves Direct Search Algorithm:

12. Moisture content (%),
13. Resin content (%),
14. Panel density (pcf),

15. Press time (minutes),

16. Minimum quality (eg. internal bond) desired,

Parameters required for Everett's method of Lagrange Multipliers:

17. The value for LAMBDA,

Miscellaneous:

18. YES/NO answers to questions posed by the model. eg:

'Would you like to continue this analysis?'

'Would you like to change the value of LAMBDA?'.

7.2 Model Outputs

Output from **MAXPRESS** includes production resource levels:

1. Moisture Content (% of O.D. panel weight),

2. Resin Content (% of O.D. panel weight),

3. Panel Density (pcf),

4. Press Time (minutes),

Parameters relating to the Lagrange optimization:

5. Value of the Lagrange Function,

6. Value of the Lagrange Multiplier (λ; printed at start and end of analysis only),

7. Value of the Objective (Payoff) Function (Dollars/8-hour shift; net of variable costs but does not include fixed costs),

8. Value of the Constraint (Quality) Function (Internal Bond in psi for base case, but any other suitable measure of quality such as MOE or MOR could be easily

substituted).

Output is printed at the start of the analysis, at intermediate solutions (base points) in the pattern search routine, at the optimum solution for the particular value of λ used, and when the **Gap Search Routine** is invoked.

7.3 The Role of LAMBDA

LAMBDA (λ), the Lagrange multiplier, represents the marginal value per unit of resource (panel quality, measured by internal bond; see **Economic Significance of the Lagrange Multiplier** in Chapter 5). Therefore, raising the value of LAMBDA will generally raise the level of internal bond in the optimum solution provided by **MAXPRESS** because the user has implied that panel quality has more value (hence, more quality and a higher level of internal bond at the optimum). The reverse is true when LAMBDA is lowered. An exception to this occurs when the range of values for LAMBDA crosses a gap region.

7.4 Using the Model - A Sample Run

In order to better demonstrate the use of **MAXPRESS**, the following narrative of a sample run of **MAXPRESS** is provided (the actual run is found in **APPENDIX IV**).

After entering APL mode, and loading the appropriate program and data workspaces, the user enters the command 'START', to initiate execution of **MAXPRESS**. The program

prompts the user for required inputs, and then prints initial, intermediate, and final output results. At this point, the user may stop the analysis, invoke the Gap Search Routine, or change user specified parameters and re-run the program.

In the example provided (**APPENDIX IV**), the user enters the required input (pages 103 and 104), and receives output for this mix of inputs and value of LAMBDA (λ) (page 105). The resulting value for internal bond is 32.909 psi, with variable profit/shift of $10150. As an example, consider the desired level of internal bond to be 42 psi (the CSA standard is 40.6 psi; National Standard of Canada 1978). To achieve this level, the model must be re-run, with a higher value for LAMBDA. In the example, LAMBDA is raised from 150 to 160. The solution (page 106) shows internal bond of 48.282 psi, and variable profit/shift of $7810. This level of internal bond is somewhat high, so the model is re-run with LAMBDA of 155 (page 107) because this implies a lower value for panel quality. The resulting solution is the same as for the previous value of Lambda, so the model is run again with LAMBDA of 152.5 (page 108). The solution for this level of LAMBDA has internal bond of 41.068 psi, and variable profit/shift of $8910. This is very close to the desired level of LAMBDA, but if 42 psi was considered the absolute minimum level of internal bond allowed, the model would have to be re-run. The value of LAMBDA could be adjusted upwards slightly, and the model re-run as before,

but this is a rather time consuming effort considering how close the last level of internal bond is to the desired level. Instead of relying on trial and error to adjust the level of internal bond by such a small amount, the Gap Search Routine was invoked using a perturbation depth of one (page 109). The resulting solution has internal bond equal to 42.576 psi and variable profit/shift of $8576. This is the optimal solution for this selection of input parameters, and is as close to the desired level of internal bond as can be obtained with the discrete constraint data used (see **Method for Handling Gaps** in Chapter 5). This search (and the searches in the remainder of this analysis) was started from several different base points, once the level of internal bond was close to the desired level, to help ensure that a true global optimum was found. Because the global optimum had been found, in all cases, output from these searches is not included in **APPENDIX IV**.

This analysis was continued (page 110), with the cost of resin being raised from $0.70/pound (first case) to $1.00/pound. The value of LAMBDA remained the same (152.5), and the model was re-run (page 111). In this case, internal bond was 45.892, and variable profit/shift was $6487. Since this level of internal bond was close to the desired level of 42 psi, it was again decided to use the Gap Search Routine, this time using a perturbation depth of three, instead of one as in the last case, because of the greater difference between the last level of internal bond (45.892

psi) and the desired level of internal bond (42 psi) (page 112). The resulting solution provides internal bond of 42.408 psi, and variable profit/shift of $6762. It is interesting to note that a jump in resin cost of $0.30/pound (from $0.70 to $1.00) resulted in a decrease of variable profit/shift of $1814 (from $8576 to $6762), and changed the optimal levels of moisture content (from 7% to 7.5%), resin content (from 2.5% to 2.125%), and press time (from 4 min. to 4.5 min.). This illustrates the sensitivity of optimal operating policy (and profits) to changes in the costs of resin, one of the four decision variables.

This run was continued with changes to the input parameters (page 113), in order to illustrate a gap. The first solution, with LAMBDA at 90 (page 114) had internal bond of 55.598 psi and variable profit/shift of $1655. LAMBDA was dropped to 87, and the model re-run. This produced a solution (page 115) with internal bond of 1.800 psi and variable profit/shift of $7490. Another run, with LAMBDA at 88, produced a solution (page 116) that was identical to the first solution, with LAMBDA at 90. Subsequent runs (not shown in **APPENDIX IV**), with the value of LAMBDA varied between 87 and 88, failed to produce any new base points. This indicated that a gap existed in the area of interest, and that further manipulation of LAMBDA would not likely produce an acceptable solution. In practice, the author found that reducing the difference between consecutive levels of LAMBDA to an interval of less

than one unit (eg. between 87 and 88 in the case above) was not justified because of the effort this requires, and because, in all cases tested, no new base points were discovered using this strategy. Because the gap was large, another run was made (page 117) to ensure that no base points existed which would produce a value for internal bond closer to the desired value. Minimum internal bond, a parameter which should be set at 0 for standard runs of **MAXPRESS**, was set at 42. When the pattern search reaches the minimum level for internal bond, it performs exploratory moves only. This action could, in some instances, reveal a new base point. It is conceivable, with some irregular functions, that a true base point (i.e. the true maximum of the Lagrange function for a particular value of LAMBDA) could be skipped over by a pattern move, particularly if the pattern move is large. Pattern moves get larger, or 'accelerate', once a pattern is established (see **Pattern Moves**), but exploratory moves are always the same size (equal to the step size of the discrete constraint data) in **MAXPRESS**. Thus, it is impossible for an exploratory move to skip over a true basepoint. A true base point would have a higher value for the Lagrange function than the previous solution obtained through a normal application of **MAXPRESS**. Finding a new base point would narrow the gap, thereby helping to find the best solution for the quality level desired, even if the Gap Search Routine still has to be used. In the example, no additional base points were

discovered. This strategy would have to be used only where gaps are very large (a subjective assessment, which can only be made on the basis of experience with **MAXPRESS**). In fact, the author discovered only one case, in numerous runs of **MAXPRESS**, where a new base point was revealed using this strategy. In the example, the gap was small enough to evaluate directly with the Gap Search Routine, and this was subsequently done (page 118). The final solution has internal bond of 42.118 and variable profit/shift of $2855. At this point, program execution was terminated.

8. MODEL TESTING

Two components of **MAXPRESS** were tested; the main routine, and the Gap Search Routine. Testing of the main routine involved the arbitrary selection of a differentiable function with three independent variables for use as the objective function. Another differentiable function, also with three independent variables, was chosen as the constraint function, and was used to fill a 30 x 50 x 30 (= 45000 elements) data matrix (one dimension for each independent variable), using an arbitrarily selected step size for each independent variable. **MAXPRESS** was then used to optimize the objective function, subject to the constraint data matrix. These results were compared to the results obtained by solving for the optimum using differential calculus. **MAXPRESS** provided results comparable to those obtained directly. Naturally, there was a slight difference due to the discrete nature of the constraints, and the subsequent discrete nature of solutions.

Several gaps were encountered using the objective function and constraint data variable developed for this project. Testing was conducted on one of these gaps by constructing a complete list of possible solutions, selecting the optimal solution, and comparing this to the result provided by the Gap Search Routine. For the gaps tested, the Gap Search Routine always provided the optimal solution with a perturbation depth of three and, in most cases, a perturbation depth of only one or two was required.

MAXPRESS appears to perform well, solving the trial problems in all cases tested, but it is not absolutely fail proof. While the model performed well in all of the tests and trial runs conducted, it is possible that non-optimal solutions could be generated, particularly with the use of unusual constraint and objective relationships. However, if reasonable precautions are taken (such as starting the pattern search from various base points, once it is thought that an optimal solution has been found), the generation of true optimal solutions should almost always occur.

A final observation is that **MAXPRESS** is easy to use. Once the initial objective function and constraint data variable are set up (and this would have to be done just once for each mill configuration), the user has only to respond to queries from the computer, and vary the level of LAMBDA to achieve the optimal solution for the desired level of internal bond.

9. CONCLUSION AND RECOMMENDATIONS

Based on the testing conducted, and the numerous trial runs undertaken with various inputs, it appears that **MAXPRESS** performs very well in the constrained optimization of the waferboard press cycle.

In addition, **MAXPRESS** meets four specific design considerations established at the initiation of this project. Namely:

- **MAXPRESS** accepts non-differentiable, non-linear, and discontinuous objective functions;
- **MAXPRESS** accepts constraint relationships in the form of discrete data;
- **MAXPRESS** is an optimization, not simulation, model;
- **MAXPRESS** is easy to use, even for personnel with no formal training in computer programming or operations research.

As it exists, **MAXPRESS** has several potential uses, but these will depend on a refinement of both the objective function and the constraint data variable. The usefullness of the procedures developed for the optimization of the press cycle is far more important than the actual profit function or panel quality data assembled for this project. One major use could be the identification of optimal operating policy (in terms of resin content, moisture content, press time, and panel density) in response to changes in cost for different factors of production. For example, one might pose the question; 'If resin prices increase 15%, should operating policy be changed (perhaps

through lower resin content, and higher press time)?' Another significant use could be the testing of different resins based on their price, and on what is known about their properties. Other sensitivity analyses could be conducted to test the effects of changes in other factors of production.

Several recommendations can be made for future research:

1. A complete waferboard mill model should be constructed, using **MAXPRESS** as a central portion, so that the entire production process can be examined. Mill design and re-design questions could then be addressed, and the implications of operating policy decisions resulting from **MAXPRESS** could be assessed from the entire mill point of view. For instance, changes in press time will affect the entire mill throughput. A complete mill model would allow one to gauge the impact of these changes, and to predict whether the rest of the mill could keep up with the press.

    The complete mill model should probably be a queuing model based on the work of Carino and Bowyer (1979, 1981). Their model provides optimization, using the Hooke-Jeeves Direct Search Algorithm, as well as simulation of the queuing system. The work of Rosenshine and Chandra (1975a, 1975b) could be useful for queues which have batch arrivals (such as the press).

2. Efforts should be devoted to refining the objective

(payoff) function and the constraint data variable, as they are currently only preliminary versions designed to illustrate the operation of **MAXPRESS**. If other production variables are deemed important to panel quality (eg. press closure rate and pressure, wafer dimensions etc.), appropriate data should be assembled and included as new dimensions to the constraint data variable. In addition, data should be assembled for different panel thicknesses.

Refinements to the objective function could be implemented to allow the comparison of various fuels (or wood waste as a fuel). In addition, it might be useful to break down the 'other variable costs' category into several components, and allocate them directly to production. Another significant improvement would be to allow for variable down time, and variable waste factors. The waste factors could represent losses at different stages of the waferboard production process (eg. loss of panel at the trim saws; loss of wood at the debarker; etc.).

The changes suggested here would probably be best achieved by working in cooperation with personnel of a waferboard production company.

3. New panel quality constraints should be added to **MAXPRESS**, or the current constraint (internal bond) should be replaced, if other constraints are deemed important. Other useful panel quality constraints could

include MOR and MOE.

4. **MAXPRESS** should be translated into FORTRAN and, possibly, other popular languages as well. While APL is extremely useful for developing an optimization model, it is not the best language to promote to waferboard production companies. APL is not available on many small computers, and where it is available, the workspace size (APL equivalent of memory), would likely be inadequate to run **MAXPRESS**. A FORTRAN version of **MAXPRESS** might also be cheaper to run than the APL version.
5. A useful option to include in **MAXPRESS** would be the possibility for a complete breakdown of production costs into categories such as fuel, resin, labour etc. This option would require an improved objective function.

In conclusion, it is evident that **MAXPRESS** currently has several potential uses, and that there are several areas where the model could be significantly improved. Throughout this study, emphasis has been placed on producing a practical, usable tool for the waferboard industry. **MAXPRESS** appears to be such a tool, but its ultimate test will be acceptance and use by the waferboard industry.

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11. APPENDIX I - SCHEMATIC DIAGRAM OF WAFERBOARD PRODUCTION PROCESS

Figure 1. Schematic Diagram of Waferboard Production Process

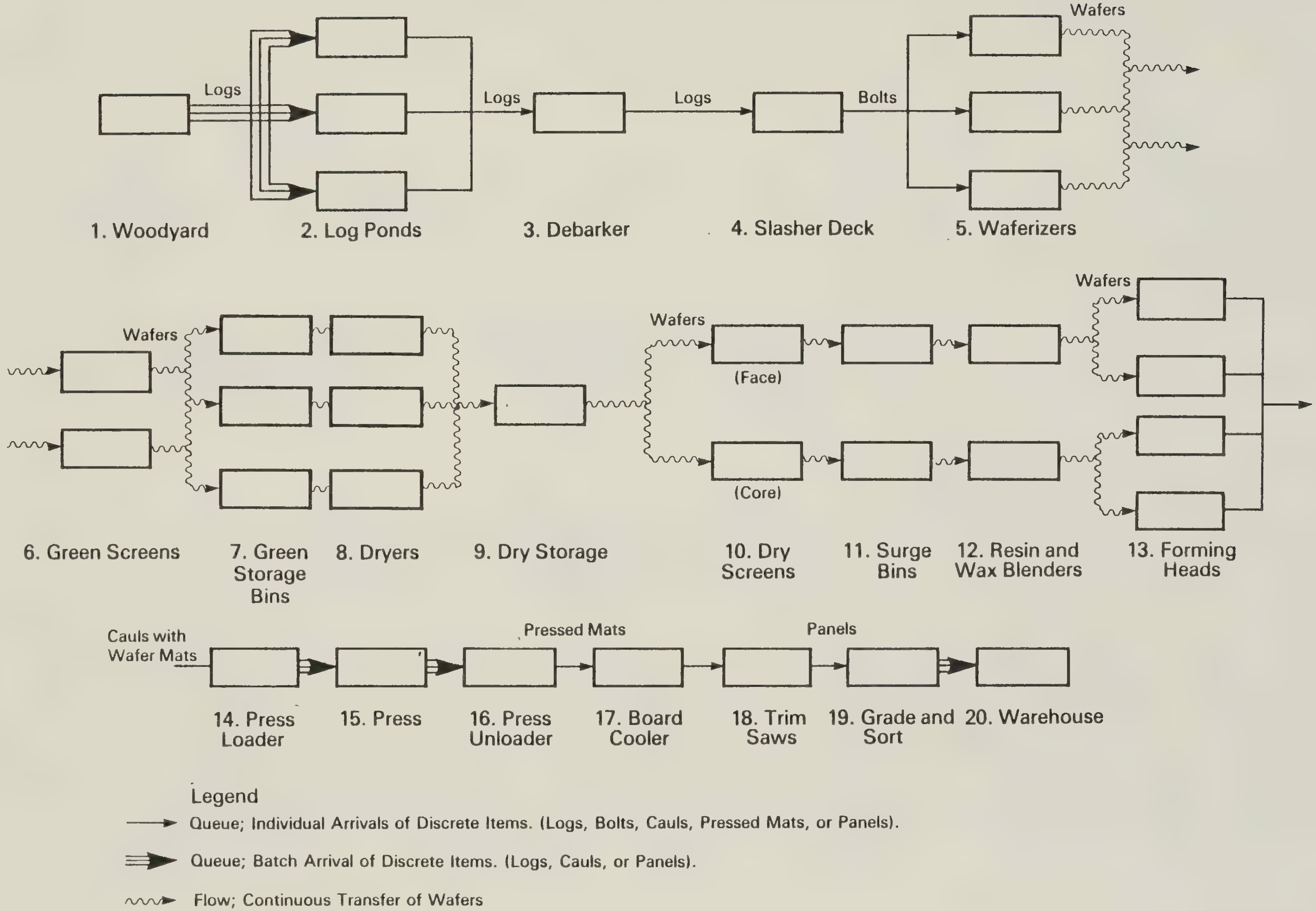
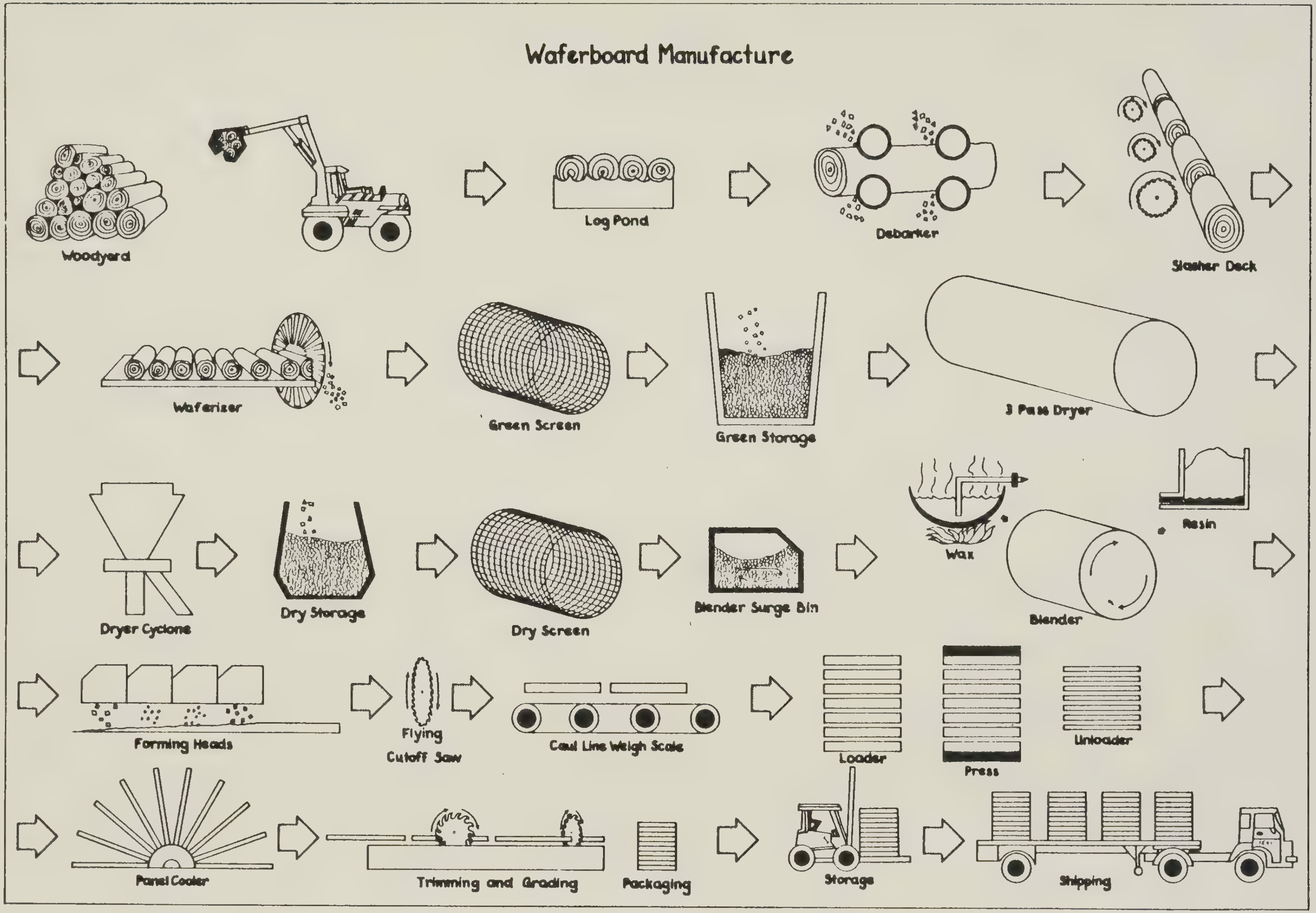


Figure 2. Waferboard Manufacture



12. APPENDIX II - LISTING OF FUNCTIONS USED IN MAXPRESS

SAVED 11:25:43 06/23/82

```
.
.  MAXPRESS
.
.
.
.                                   AUG  4,1982
.
.                                       8:54:58
.
.........................................
```

```
**** GROUPS ******
```

DIRECTORY FOR MAXPRESS

```
**** F U N C T I O N S ******

BASEQ          GAP            LTR            PARAM
BY             GAPQ           MATRIX1        ROW
COL            IF             MATRIX2        SEARCHMAX
CONFCN         IFNOTO         MATRIX3        SELECT
COSTQ          IFYESTO        MESSAGE        START
EXPLAIN        INITIAL        MINQ           STATUSQ
EXPLOREMAX     INTERPOLATE    OBJFCN         STEPSET
FUNCTION       LAMBDAQ        ON1            VARIABLES

**** V A R I A B L E S ******
```

(NAMES WITH UNDERLINED CHARACTERS ARE NOT LISTED.)

```
****  BASEQ                                                     BASEQ

∇ BASEQ

''

→0 IFNOTO 'WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH?

FIRSTBASE←INITIAL,¯1↑FIRSTBASE

''

⍝

⍝ ASKS QUESTION FOR CHANGING STARTING POINT OF SEARCH

⍝


****  BY                                                        BY

  BY  :(((1 0 ×ρω)⌈ρα)↑α),((1 0×ρα)⌈ρω)↑ω
      :(0=0\0/,α←COL α)≠(0=0\0/,ω←COLω)
      :(⍒α) BY (⍒ω)
⍝
⍝  CREATE A MATRIX FROM α AND ω
⍝  BY FIRST CONVERTING THEM TO MATRICES AND THEN
⍝  ADJUSTING THEIR ROW  SIZES TO MATCH
⍝  AND PLACING α TO LEFT OF ω.
⍝  IF THEY DIFFER IN TYPE THEY ARE CONVERTED
⍝  TO CHARACTER FORM.

****  COL                                                       COL

COL:(2↑(ρω),1 1)ρω
⍝
⍝ RESTRUCTURE ω AS MATRIX WITH AT LEAST ONE COLUMN.
⍝   (ONLY FIRST TWO COORDINATES OF STRUCTURE ARE
⍝       RETAINED.)
⍝
```

**** CONFCN CONFCN

```
∇ OUT←CONFCN B;COUNT;MAX;COUNT;I;MAXI;MATR;MAX;COUNTER;V;W
COUNTER←1
B←ROW B
MAXI←1↑⍴B
MATR←(1↑⍴B)⍴0
BEGIN:
→END IF COUNTER>MAXI
V←B[COUNTER;]
I←(⍴,V)⍴0
MAX←⍴,V
COUNT←1
START:
→SET IF COUNT>MAX
I[COUNT]←(V[COUNT]=CONSTEP[COUNT;])/⍳⍴CONSTEP[COUNT;]
COUNT←COUNT+1
→START
SET:
MATR[COUNTER]←CONMAT[I[1];I[2];I[3];I[4]]
COUNTER←COUNTER+1
→BEGIN
END:
OUT←MATR
⍝
⍝ CONFCN SELECTS THE APPROPRIATE VALUE FOR INTERNAL BOND
⍝ FROM THE CONSTRAINT MATRIX (CONMAT) BY LOCATING EACH
⍝ OF THE FOUR DECISION VARIABLES (RC, MC, DEN, PRESS)
⍝ ALONG THE CONSTRAINT STEP SIZE VECTORS FOUND IN
⍝ CONSTEP.
⍝
```

**** COSTQ COSTQ

```
∇ COSTQ
''
→0 IFNOTO 'WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES?'
COST←PARAM
''
⍝
⍝ ASKS QUESTION FOR CHANGING THE VARIABLE COST FIGURES.
⍝
```

**** EXPLAIN EXPLAIN

```
∇ EXPLAIN
''
''
'MAXPRESS IS A TOTALLY INTERACTIVE COMPUTER PROGRAM,'
'DESIGNED FOR THE OPTIMIZATION OF THE PRESS CYCLE'
'OF A TYPICAL WAFERBOARD MILL.'
''
'TWO TECHNIQUES ARE USED IN THE OPTIMIZATION ROUTINE.'
'THE FIRST TECHNIQUE, THE HOOKE-JEEVES DIRECT SEARCH ALGORITHM,'
'ALLOWS THE OPTIMIZATION OF NON-DIFFERENTIABLE, NON-LINEAR,'
'DISCONTINUOUS, OR UNDEFINED FUNCTIONS, OR FUNCTIONAL RELATIONSHIPS'
'DEFINED BY DISCRETE DATA.  THE SECOND TECHNIQUE EMPLOYED IS'
'EVERETTS METHOD OF LAGRANGE MULTIPLIERS.  THIS METHOD TRANSFORMS'
'A CONSTRAINED OPTIMIZATION PROBLEM INTO AN UNCONSTRAINED'
'OPTIMIZATION PROBLEM, AND THUS ALLOWS THE USE OF THE'
'HOOKE-JEEVES DIRECT SEARCH ALGORITHM.'
''
'TWO TYPES OF INPUT ARE REQUIRED TO RUN MAXPRESS:'
'1. GENERAL INPUT'
'2. USER PROVIDED INPUT.'
''
'THERE ARE TWO MAJOR PIECES OF GENERAL INPUT REQUIRED TO'
'RUN MAXPRESS; 1) AN OBJECTIVE FUNCTION AND; 2) A CONSTRAINT'
'RELATIONSHIP (IN THE FORM OF DISCRETE DATA).  THE OBJECTIVE'
'FUNCTION PROVIDES THE PAYOFF RELATIONSHIP FOR THE PARTICULAR'
'MILL IN QUESTION, WHILE THE CONSTRAINT DATA PROVIDES THE'
'QUALITY RELATIONSHIP BETWEEN DECISION VARIABLES (EG. PRESS'
'TIME, RESIN CONTENT, MOISTURE CONTENT, PANEL DENSITY) AND'
'SOME MEASURE OF QUALITY SUCH AS INTERNAL BOND.  THE OBJECTIVE'
'FUNCTION IS DEFINED AS AN APL FUNCTION CALLED OBJFCN, WHILE'
'THE CONSTRAINT DATA IS STORED IN AN APL DATA VARIABLE'
'CALLED CONMAT.'
''
'MAXPRESS PROMPTS THE USER FOR THE FOLLOWING COST AND REVENUE'
'INPUTS (USER PROVIDED INPUT):'
''
' 1. PANEL THICKNESS (INCHES; CURRENTLY THE USER CAN ONLY'
'    USE .4375 INCHES (7/16) DUE TO A LACK OF DATA FOR PANEL'
'    QUALITY RELATIONSHIPS TO PRODUCTION VARIABLES),'
' 2. RESIN COST (DOLLARS/POUND), '
' 3. WAX COST (DOLLARS/POUND),'
' 4. WOOD COST (DOLLARS/O.D. POUND OF WAFERS),'
' 5. FUEL COST (DOLLARS/MCF NATURAL GAS),'
' 6. OTHER VARIABLE COSTS (DOLLARS/MSF WAFERBOARD),'
' 7. SELLING PRICE AT THE FACTORY GATE (DOLLARS/MSF WAFERBOARD),'
' '
'THE MINIMUM POSSIBLE VALUE, MAXIMUM POSSIBLE VALUE, AND STEP'
'SIZE (FOR THE HOOKE-JEEVES DIRECT SEARCH ALGORITHM - STEP SIZE'
'MUST EQUAL THE INTERVAL SIZE OF THE CONSTRAINT MATRIX), FOR'
'EACH OF THE FOLLOWING VARIABLES:'
''
' 8. MOISTURE CONTENT OF THE PANEL (PERCENT OF O.D. PANEL WEIGHT),'
' 9. RESIN CONTENT OF THE PANEL (PERCENT OF O.D. PANEL WEIGHT),'
'10. PANEL DENSITY (PCF), '
'11. PRESS TIME (MINUTES),'
''
```

```
'THE STARTING POINT FOR THE HOOKE-JEEVES DIRECT SEARCH ALGORITHM:'
''
'12. MOISTURE CONTENT (PERCENT),'
'13. RESIN CONTENT (PERCENT),'
'14. PANEL DENSITY (PCF),'
'15. PRESS TIME (MINUTES),'
'16. MINIMUM QUALITY (EG. INTERNAL BOND) DESIRED; SHOULD BE SET'
'     TO 0 IN MOST CASES; ONLY EXCEPTION IS WHERE YOU WANT TO'
'     EXPLORE THE AREA OF INTEREST USING EXPLORATORY MOVES TO'
'     SEE IF THERE ARE NEW BASE POINTS; FOR INSTANCE, IN GAP '
'     REGIONS,'
''
'PARAMETERS REQUIRED FOR EVERETTS METHOD OF LAGRANGE MULTIPIERS:'
''
'17. THE VALUE FOR LAMBDA, THE LAGRANGE MULTIPLIER,'
''
'MISCELLANEOUS:'
''
'18. YES/NO ANSWERS TO QUESTIONS POSED BY THE MODEL.'
''
```

**** *EXPLOREMAX* *EXPLOREMAX*

```
∇ EXPLOREMAX;COUNT;M
COUNT←1
M←ρ(¯1↓TEMPBASE)
START:
→0 IF COUNT>M
TEMPBASE[COUNT]←TEMPBASE[COUNT]+STEPSIZE[COUNT]
→OUT IF(FUNCTION TEMPBASE)>TEST
TEMPBASE[COUNT]←TEMPBASE[COUNT]-2×STEPSIZE[COUNT]
→OUT IF(FUNCTION TEMPBASE)>TEST
TEMPBASE[COUNT]←TEMPBASE[COUNT]+STEPSIZE[COUNT]
→COUNTER
OUT:
TEST←FUNCTION TEMPBASE
COUNTER:
COUNT←COUNT+1
→START
⍝
⍝ EXPLOREMAX PERFORMS EXPLORATORY MOVES FOR THE
⍝ HOOKE-JEEVES DIRECT SEARCH ALGORITHM, WHERE THE
⍝ OBJECTIVE IS FUNCTION MAXIMIZATION.
⍝
```

**** *FUNCTION* *FUNCTION*

```
∇ OUT←FUNCTION V;L;COUNT
L←¯1↑V
V←¯1↓V
→RESET IF(∨/V<MIN)∨(∨/V>MAX)
⍝ →INTER IF MODE=1
OUT←(COST OBJFCN V)-L×(CONFCN V)
→0
INTER:
OUT←(COST OBJFCN V)-L×(INTERPOLATE V)
→0
RESET:
OUT←TEST
⍝
⍝ FUNCTION CHECKS THE DECISION VARIABLES TO SEE IF
⍝ THEY ARE WITHIN THE ACCEPTABLE RANGE, AND THEN
⍝ CALCULATES THE LAGRANGE SOLUTION FOR THIS COMBINATION
⍝ OF DECISION VARIABLES.
⍝ OBJFCN IS CALLED TO CALCULATE THE PROFIT/SHIFT.
⍝ CONFCN IS CALLED TO DETERMINE INTERNAL BOND.
⍝ INTERPOLATE IS NOT CURRENTLY USED, BUT COULD
⍝ BE VALUABLE IS LINEAR INTERPOLATION BETWEEN
⍝ STEPS OF THE DECISION VARIABLES WAS DEEMED IMPORTANT.
⍝
```

**** GAP GAP

```
∇ OUT←B GAP Q;BASE1;OB;CO;L;DIFF;BASE
BASE←B
BASE1←(COST OBJFCN BASE)-LAMBDA×CONFCN BASE
OB←COST OBJFCN Q
CO←CONFCN Q
L←OB-LAMBDA×CO
DIFF←L-BASE1
OUT←DIFF BY L BY OB BY CO BY Q
⍝
⍝ PERFORMS THE SAME TASKS AS FUNCTION,
⍝ BUT FOR THE GAP SEARCH ROUTINE.
⍝
```

```
****  GAPQ                                                              GAPQ

∇ OUT←GAPQ;A;B;BASE;N
''
→END IFNOTO 'WOULD YOU LIKE TO PERFORM A GAP SEARCH?'
''
'**********************************************************************
****'
'************************      GAP SEARCH ROUTINE      ***************
****'
'**********************************************************************
****'
''
BASE←INITIAL
MINQ 0
LAMBDAQ 0
''
'ENTER THE VALUE FOR PERTURBATION DEPTH (MAXIMUM IS 3)'
''
N←⎕
→ONE IF N=1
→TWO IF N=2
→THREE IF N=3
ONE:
A←BASE SELECT BASE GAP MATRIX1 BASE
→CONTINUE
TWO:
A←BASE SELECT BASE GAP MATRIX2 BASE
→CONTINUE
THREE:
A←BASE SELECT BASE GAP MATRIX3 BASE
→CONTINUE
CONTINUE:
```

```
BASEPOINT←A[5 6 7 8],LAMBDA
OUT←1
→0
END:
OUT←0
⍝
⍝ THIS IS THE GAP SEARCH ROUTINE.
⍝ APPROPRIATE DATA IS OBTAINED FROM THE
⍝ USER. THEN, FUNCTIONS ARE CALLED DEPENDING
⍝ ON THE PERTURBATION DEPTH REQUESTED.
⍝
```

```
****  IF                                                          IF

   1| IF:ω/α
   2| ⍝
   3| ⍝   RETURNS α IF ω IS TRUE OTHERWISE RETURNS EMPTY VECTOR
   4| ⍝


****  IFNOTO                                                  IFNOTO

   0| ∇ R←LABEL IFNOTO QUERY;ANS;T
   1| ⍞←QUERY,'  '
   2| ANS←4↑(ANS≠' ')/ANS←⍞
   3| →(R←(∧/(ANS='N   '))∨∧/(ANS='NO  '))/FIN
   4| →((∧/(ANS='Y   '))∨∧/(ANS='YES '))/FIN
   5| →(∧/ANS='STOP')/STP
   6| 'IMPROPER RESPONSE, REPLY Y OR YES FOR YES, N OR NO FOR NO'
   7| 'TRY AGAIN'
   8| →2
   9| STP:R←'STOP'
  10| 'EXECUTION INTERRUPTED, REMEMBER TO CLEAR THE STATE INDICATOR'
  11| →0
  12| FIN:R←R/LABEL
  13| ⍝
  14| ⍝ ASKS A QUESTION (QUERY), AND EXECUTES
  15| ⍝ A RESPONSE IF THE ANSWER (PROVIDED BY
  16| ⍝ THE USER) IS NO.
  17| ⍝


****  IFYESTO                                                IFYESTO

   0| ∇ R←LABEL IFYESTO QUERY;ANS;T
   1| ⍞←QUERY,'  '
   2| ANS←4↑(ANS≠' ')/ANS←⍞
   3| →(R←(∧/(ANS='Y   '))∨∧/(ANS='YES '))/FIN
   4| →((∧/(ANS='N   '))∨∧/(ANS='NO  '))/FIN
   5| →(∧/ANS='STOP')/STP
   6| 'IMPROPER RESPONSE, REPLY Y OR YES FOR YES, N OR NO FOR NO'
   7| 'TRY AGAIN'
   8| →2
   9| STP:R←'STOP'
  10| 'EXECUTION INTERRUPTED, REMEMBER TO CLEAR THE STATE INDICATOR'
  11| →0
  12| FIN:R←R/LABEL
  13| ⍝
  14| ⍝ ASKS A QUESTION (QUERY), AND EXECUTES
  15| ⍝ A RESPONSE IF THE ANSWER (PROVIDED BY
  16| ⍝ THE USER) IS YES.
  17| ⍝
```

**** INITIAL INITIAL

```
∇ OUT←INITIAL;A
''
'ENTER, IN ORDER, VALUES FOR EACH PROCESS VARIABLE:'
''
'MOISTURE CONTENT (PERCENT)'
''
A←⎕
''
'RESIN CONTENT (PERCENT)'
''
A←A,⎕
''
'PANEL DENSITY (PCF)'
''
A←A,⎕
''
'PRESS TIME (MINUTES)'
''
A←A,⎕
''
OUT←A
⍝
⍝ I/O FUNCTION FOR INPUTTING VALUES FOR
⍝ THE PROCESS (DECISION) VARIABLES.
⍝
```

```
****  INTERPOLATE                                                          INTERPOLATE

∇ OUT←INTERPOLATE V;LOWER;UPPER;L;L1;U;U1;MAX;COUNT;DIFF;MARK
L←U←L1←U1←(ρV)ρ0
MARK←0
MAX←ρV
COUNT←1
START:
→SET IF COUNT>MAX
→RESTART IF(+/V[COUNT]=CONSTEP[COUNT;])>0
U1[COUNT]←1↑(V[COUNT]<CONSTEP[COUNT;])/CONSTEP[COUNT;]
U[COUNT]←(U1[COUNT]=CONSTEP[COUNT;])/ιρCONSTEP[COUNT;]
L[COUNT]←U[COUNT]-1
L1[COUNT]←CONSTEP[COUNT;L[COUNT]]
MARK←COUNT
COUNT←COUNT+1
→START
RESTART:
U[COUNT]←L[COUNT]←(V[COUNT]=CONSTEP[COUNT;])/ιρCONSTEP[COUNT;]
U1[COUNT]←L1[COUNT]←0
COUNT←COUNT+1
→START
SET:
→SET1 IF MARK=0
LOWER←CONMAT[L[1];L[2];L[3];L[4]]
UPPER←CONMAT[U[1];U[2];U[3];U[4]]
DIFF←UPPER-LOWER
OUT←LOWER+DIFF×(V[MARK]-L1[MARK])÷U1[MARK]-L1[MARK]
→0
SET1:
OUT←CONMAT[L[1];L[2];L[3];L[4]]
⍝
⍝ CURRENTLY UNUSED.  PROVIDES INTERPOLATION
⍝ CAPABILITIES FOR THE HOOKE-JEEVES ALGORITHM.
⍝

****  LAMBDAQ                                                              LAMBDAQ

∇ LAMBDAQ B;L
→SET IF B=0
''
→SET IFYESTO 'WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA?'
→0
SET:
''
'ENTER THE VALUE FOR LAMBDA'
''
LAMBDA←⎕
L←0-LAMBDA
FIRSTBASE←(¯1↓FIRSTBASE),L
''
⍝
⍝ I/O FUNCTION FOR CHANGING THE VALUE
⍝ OF LAMBDA, THE LAGRANGE MULTIPLIER.
⍝
```

```
****  LTR                                                              LTR

 LTR:α+.×ω
 ⍝ LINEAR TRANSFORMATION, OR PRODUCT SUM OF α WITH ω


****  MATRIX1                                                      MATRIX1

 ∇ OUT←MATRIX1 N;A;B;C;D;M;S;I
 I←1
 S←STEPSIZE
 A←81ρ(27ρN[4]+S[4]),(27ρN[4]),(27ρN[4]-S[4])
 B←81ρ(9ρN[3]+S[3]),(9ρN[3]),(9ρN[3]-S[3])
 C←81ρ(3ρN[2]+S[2]),(3ρN[2]),(3ρN[2]-S[2])
 D←81ρ(N[1]+S[1]),N[1],(N[1]-S[1])
 M←D BY C BY B BY A
 LOOP:
 →END IF I>¯1↑ρM
 W←((M[;I]≤MAX[I])∧(M[;I]≥MIN[I]))/⍳1↑ρM
 M←M[W;]
 I←I+1
 →LOOP
 END:
 OUT←M
 ⍝
 ⍝ SETS UP MATRIX WITH ALL POSSIBLE COMBINATIONS
 ⍝ OF DECISION VARIABLES FOR PERTURBATION
 ⍝ DEPTH OF ONE.
 ⍝
```

```
∇ OUT←MATRIX2 N;A;B;C;D;M;W;I
I←1
S←STEPSIZE
A←625ρ(125ρN[4]+2×S[4]),(125ρN[4]+S[4]),(125ρN[4]),(125ρN[4]-S[4]),(125ρN[4]-2×S[4])
B←625ρ(25ρN[3]+2×S[3]),(25ρN[3]+S[3]),(25ρN[3]),(25ρN[3]-S[3]),(25ρN[3]-2×S[3])
C←625ρ(5ρN[2]+2×S[2]),(5ρN[2]+S[2]),(5ρN[2]),(5ρN[2]-S[2]),(5ρN[2]-2×S[2])
D←625ρ(N[1]+2×S[1]),(N[1]+S[1]),(N[1]),(N[1]-S[1]),(N[1]-2×S[1])
M←D BY C BY B BY A
LOOP:
→END IF I>¯1↑ρM
W←((M[;I]≤MAX[I])∧(M[;I]≥MIN[I]))/⍳1↑ρM
M←M[W;]
I←I+1
→LOOP
END:
OUT←M
⍝
⍝ SETS UP MATRIX WITH ALL POSSIBLE COMBINATIONS
⍝ OF DECISION VARIABLES FOR PERTURBATION
⍝ DEPTH OF TWO.
⍝
```

```
∇ OUT←MATRIX3 N;A;B;C;D;M;W;I
S←STEPSIZE
I←1
A←2401ρ(343ρN[4]+3×S[4]),(343ρN[4]+2×S[4]),(343ρN[4]+S[4]),(343ρN[4]),
 (343ρN[4]-S[4]),(343ρN[4]-2×S[4]),(343ρN[4]-3×S[4])
B←2401ρ(49ρN[3]+3×S[3]),(49ρN[3]+2×S[3]),(49ρN[3]+S[3]),(49ρN[3]),(49ρ
N[3]-S[3]),(49ρN[3]-2×S[3]),(49ρN[3]-3×S[3])
C←2401ρ(7ρN[2]+3×S[2]),(7ρN[2]+2×S[2]),(7ρN[2]+S[2]),(7ρN[2]),(7ρN[2]-
S[2]),(7ρN[2]-2×S[2]),(7ρN[2]-3×S[2])
D←2401ρ(N[1]+3×S[1]),(N[1]+2×S[1]),(N[1]+S[1]),(N[1]),(N[1]-S[1]),(N[1
]-2×S[1]),(N[1]-3×S[1])
M←D BY C BY B BY A
LOOP:
→END IF I>¯1↑ρM
W←((M[;I]≤MAX[I])∧(M[;I]≥MIN[I]))/⍳1↑ρM
M←M[W;]
I←I+1
→LOOP
END:
OUT←M
⍝
⍝ SETS UP MATRIX WITH ALL POSSIBLE COMBINATIONS
⍝ OF DECISION VARIABLES FOR PERTURBATION
⍝ DEPTH OF THREE.
⍝
```

```
****  MESSAGE                                                                    MESSAGE

∇ MESSAGE
''
''
'*********************************************'
'*********************************************'
'**  WAFERBOARD PRODUCTION OPTIMIZATION MODEL **'
'**          ALBERTA RESEARCH COUNCIL         **'
'**        FOREST PRODUCTS PROGRAM: FP-19     **'
'**          AUTHOR: TOM I. GRABOWSKI         **'
'**        LAST REVISION: JUNE 1, 1982        **'
'*********************************************'
'*********************************************'
' '
' '
'*****WARNING: YOUR DATA FILE MUST BE COPIED INTO THIS WORKSPACE.'
''
'ENTER ONE OF THE FOLLOWING KEYWORDS:'
''
'EXPLAIN (GIVES A DESCRIPTION OF THE PROGRAM)'
''
'START (INITIATE RUNNING OF THE PROGRAM)'
''
''
⍝
⍝ MESSAGE WHICH APPEARS ON THE SCREEN
⍝ (AS A LATENT EXPRESSION) WHEN THE USER
⍝ LOADS THIS WORKSPACE.
⍝

****  MINQ                                                                          MINQ

∇ MINQ B
→SET IF B=0
''
→0 IFNOTO 'WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND?'
SET:
''
'ENTER VALUE FOR MINIMUM INTERNAL BOND'
''
MINIMUM←⎕
''
⍝
⍝ I/O FUNCTION TO CHANGE THE MINIMUM LEVEL OF
⍝ PANEL QUALITY (INTERNAL BOND).
⍝
```

```
****  OBJFCN                                                              OBJFCN

∇ OUT←A OBJFCN B;ODWEIGHT;MC;VARCOST;REV;EXP
B←ROW B
ODWEIGHT←1.25×(0.01×100-B[;1]+B[;2]+1)×B[;3]×32×A[1]÷12
MC←(1.15×1892×A[5]÷1001132)-(0.05×1892×(A[5]÷1001132)×B[;1])
VARCOST←(A[6]×0.032)+ODWEIGHT×(A[2]×B[;2]÷100)+(A[3]×0.01)+MC+A[4]
REV←(480÷B[;4])×24×2×0.032×A[7]
EXP←(480÷B[;4])×24×2×VARCOST
OUT←REV-EXP
⍝ INPUT A: 1) PANEL THICKNESS (INCHES),
⍝          2) RESIN COST (DOLLARS/POUND),
⍝          3) WAX COST (DOLLARS/POUND),
⍝          4) WOOD COST (DOLLARS/O.D. POUND CHIPS),
⍝          5) FUEL COST (DOLLARS/MCF NATURAL GAS),
⍝          6) OTHER VARIABLE COSTS (DOLLARS/MSF),
⍝          7) SELLING PRICE (DOLLARS/MSF).
⍝ INPUT B: 1) MOISTURE CONTENT OF PANEL (PERCENT OF O.D. WEIGHT),
⍝          2) RESIN CONTENT OF PANEL (PERCENT OF O.D. WEIGHT),
⍝          3) DENSITY OF PANEL (PCF),
⍝          4) PRESS TIME (MINUTES).
⍝
⍝ VARIABLE COSTS AND QUANTITIES OF PROCESS VARIABLES ARE INPUTS,
⍝ VARIABLE REVENUE PER 8-HOUR SHIFT IS OUTPUT.
⍝ ODWEIGHT ASSUMES 25 PERCENT OF WAFERS LOST TO TRIM, ETC.
⍝

****  ON1                                                                    ON1

 ON1  :(((0 1 ×ρω)⌈ρα)↑α),[⎕IO]((0 1×ρα)⌈ρω)↑ω
      :(0=0\0/,α←ROW α)≠(0=0\0/,ω←ROWω)
      :(⍒α) ON1 (⍒ω)
⍝
⍝  CREATE A MATRIX FROM α AND ω
⍝  BY FIRST CONVERTING THEM TO MATRICES AND THEN
⍝  ADJUSTING THEIR COLUMN SIZES TO MATCH
⍝  AND PLACING α ON TOP OF ω.
⍝  IF THEY DIFFER IN TYPE THEY ARE CONVERTED
⍝  TO CHARACTER FORM.
⍝
```

```
****  PARAM                                                          PARAM

∇ OUT←PARAM;B
''
'ENTER, IN ORDER, VALUES FOR THE FOLLOWING PARAMETERS:'
''
'PANEL THICKNESS (INCHES)'
''
B←⎕
''
'RESIN COST (DOLLARS/POUND)'
''
B←B,⎕
''
'WAX COST (DOLLARS/POUND)'
''
B←B,⎕
''
'WOOD COST (DOLLARS/O.D. POUND WAFERS)'
''
B←B,⎕
''
'FUEL COST (DOLLARS/MCF NATURAL GAS)'
''
B←B,⎕
''
'OTHER VARIABLE COSTS (DOLLARS/MSF)'
''
B←B,⎕
''
'SELLING PRICE AT THE FACTORY GATE (DOLLARS/MSF)'
''
B←B,⎕
''
OUT←B
⍝
⍝ I/O FUNCTION FOR SETTING UP USER PROVIDED
⍝ INPUTS.
⍝

****  ROW                                                              ROW

ROW:(¯2↑1 1,⍴⍵)⍴⍵
⍝
⍝  RESTRUCTURE ⍵ AS MATRIX WITH AT LEAST ONE ROW.
⍝  (ONLY LAST TWO COORDINATES OF STRUCTURE ARE RETAINED.)
⍝
```

**** SEARCHMAX SEARCHMAX

```
∇ FIRSTSTEP SEARCHMAX FIRSTBASE;OLDBASE;CURRENT;STEPSAVE
STATUS←0
⍝ STEPSAVE←STEPS
INITIALIZE:
⍝ STEPS←STEPSAVE
⍝ MODE←0
BASEPOINT←FIRSTBASE
STEPSIZE←FIRSTSTEP
CURRENT←FUNCTION BASEPOINT
''
''
'**********************************************************************
****'
'                                                M.C.     R.C.    DEN.      P
RESS'
''
'STARTING POINT -  PROCESS VARIABLES:      ', 8 3 ⍕(¯1↓BASEPOINT)
'INITIAL VALUE OF LAGRANGE FUNCTION:       ', 32 3 ⍕FUNCTION BASEPOINT
'LAMBDA IS:                                ', 32 3 ⍕LAMBDA
'VARIABLE REVENUE (DOLLARS/SHIFT):         ', 32 3 ⍕COST OBJFCN BASEPOI
NT
'INTERNAL BOND (PSI) IS:                   ', 32 3 ⍕CONFCN ¯1↓BASEPOINT
START:
TEST←CURRENT
TEMPBASE←BASEPOINT
→PRINTOUT IF(CONFCN ¯1↓TEMPBASE)<MINIMUM
EXPLOREMAX
→PRINTOUT IF(CONFCN ¯1↓TEMPBASE)<MINIMUM
→PATTERN IF TEST>CURRENT
→PRINTOUT
⍝→PRINTOUT IF(+/STEPS[1;]≥STEPS[3;])=0
```

```
⍝STEPS[1;]←STEPS[1;]×STEPS[2;]
⍝STEPSIZE←,STEPS[1;]
⍝MODE←1
⍝→START
PATTERN:
→START IF(CONFCN ¯1↓TEMPBASE)<MINIMUM
OLDBASE←BASEPOINT
BASEPOINT←TEMPBASE
CURRENT←TEST
''
'INTERMEDIATE - PROCESS VARIABLES:         ', 8 3 ⍕(¯1↓BASEPOINT)
'INTERMEDIATE VALUE OF LAGRANGE FUNCTION: ', 32 3 ⍕FUNCTION BASEPOINT
'VARIABLE REVENUE (DOLLARS/SHIFT):        ', 32 3 ⍕COST OBJFCN BASEPOI
NT
'INTERNAL BOND (PSI) IS:                  ', 32 3 ⍕CONFCN ¯1↓BASEPOINT
→SKIP IF STATUS=1
TEMPBASE←(2×TEMPBASE)-OLDBASE
TEST←FUNCTION TEMPBASE
SKIP:
EXPLOREMAX
→PATTERN IF TEST>CURRENT
→START
PRINTOUT:
''
''
'*********************************************************************
****'
'OPTIMAL SOLUTION FOR LAMBDA = ', 9 3 ⍕LAMBDA
''
'                                         M.C.     R.C.    DEN.      P
RESS'
'FINAL POINT - PROCESS VARIABLES:         ', 8 3 ⍕(¯1↓BASEPOINT)
'FINAL VALUE OF LAGRANGE FUNCTION:        ', 32 3 ⍕FUNCTION BASEPOINT
```

```
'VARIABLE REVENUE (DOLLARS/SHIFT):         ', 32 3 ⍕COST OBJFCN BASEPOI
 NT
'INTERNAL BOND (PSI) IS:                   ', 32 3 ⍕CONFCN ¯1↓BASEPOINT
''
''
→OUT IFNOTO 'WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?'
T←GAPQ
→PRINTOUT IF T=1
COSTQ
BASEQ
LAMBDAQ 1
STATUSQ
MINQ 1
→INITIALIZE
''
OUT:
''
'************************  END OF ANALYSIS  ************************
 ****'
⍝
⍝ THE PRIMARY FUNCTION IN MAXPRESS.
⍝ SEARCHMAX PERFORMS THE CONSTRAINED OPTIMIZATION
⍝ OF THE WAFERBOARD PRESS CYCLE.
⍝ THIS FUNCTION SHOULD PROBABLY BE BROKEN DOWN
⍝ SO THAT I/O COMPONENTS ARE SEPARATED.
⍝
```

```
****  SELECT                                                      SELECT

  ∇ OUT←B SELECT A;T;A1;I;COUNT
  BASE←B
  A←A[⍋|A[;1];]
  A←A BY⍳1↑⍴A
  T←(A[;4]≥MINIMUM)/⍳1↑⍴A
  A←A[T;]
  A1←(⍴A)⍴0
  I←2
  COUNT←1
  A1[1;]←A[1;]
  START:
  COUNT←COUNT+1
  →END IF COUNT>1↑⍴A
  →START IF(A[⍳COUNT;3]>A[COUNT;3])∧(A[⍳COUNT;4]≥A[COUNT;4])
  A1[I;]←A[COUNT;]
  I←I+1
  →START
  END:
  T←(A1[;9]≠0)/⍳1↑⍴A1
  A1←A1[T;]
  A1←A1[⍒A1[;3];]
  OUT←A1[1;]
  ⍝
  ⍝ THIS FUNCTION IS USED BY THE GAP SEARCH
  ⍝ ROUTINE (GAPQ) TO SELECT THE ELEMENT
  ⍝ WHICH PROVIDES THE GREATEST PAYOFF WHILE
  ⍝ STILL MEETING PANEL QUALITY CONSTRAINTS.
  ⍝

****  START                                                       START

  ∇ START;A;STEPSIZE;FIRSTBASE
  ''
  ''
  'RUN DATE       ',⍕⎕TS[⍳4]
  ''
  COST←PARAM
  ''
  A←VARIABLES
  MIN←A[;1]
  MAX←A[;2]
  STEPSIZE←A[;3]
  ''
  'STARTING POINT FOR VECTOR SEARCH;'
  FIRSTBASE←INITIAL,0
  LAMBDAQ 0
  MINQ 0
  STATUSQ
  STEPSET STEPSIZE
  STEPSIZE SEARCHMAX FIRSTBASE
```

**** *STATUSQ* *STATUSQ*

```
∇ STATUSQ
''
→SET IFYESTO 'WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY?'
STATUS←0
→0
SET:
STATUS←1
⍝
⍝ AN I/O FUNCTION FOR CHANGING THE STATUS OF
⍝ THE QUESTION POSED.
⍝
```

**** *STEPSET* *STEPSET*

```
∇ STEPSET STEPSIZE;STEPS;INT;I
CONSTEP←0
STEPS←(MAX-MIN)÷STEPSIZE
I←1
START:
→OUT IF I>⍴STEPS
INT←MIN[I],MIN[I]+STEPSIZE[I]×⍳STEPS[I]
CONSTEP←CONSTEP ON1 INT
I←I+1
→START
OUT:
CONSTEP← 1 0 ↓CONSTEP
⍝
⍝ THIS FUNCTION SETS UP THE STEP SIZE
⍝ FOR THE CONSTRAINT DATA VARIABLE.
⍝
```

```
 0| ∇ OUT←VARIABLES;B;A;Q
 1| B← 4 3 ρ0
 2| ''
 3| 'ENTER, FOR EACH PROCESS VARIABLE, THE FOLLOWING PARAMETERS:'
 4| 'MINIMUM POSSIBLE VALUE, MAXIMUM POSSIBLE VALUE, STEP SIZE:'
 5| '***NOTE: STEP SIZE MUST EQUAL INTERVAL SIZE OF CONSTRAINT MATRIX.'
 6| ''
 7| 'EXAMPLE FOR MOISTURE CONTENT:'
 8| ''
 9| '   6 8 .5'
10| ''
11| 'MOISTURE CONTENT OF THE PANEL (PERCENT)'
12| ''
13| A←⎕
14| Q←11
15| →(3≠ρ,A)/ERROR
16| B[1;]←A
17| ''
18| 'RESIN CONTENT OF THE PANEL (PERCENT OF O.D. WEIGHT)'
19| ''
20| A←⎕
21| Q←18
22| →(3≠ρ,A)/ERROR
23| B[2;]←A
24| ''
25| 'PANEL DENSITY (PCF)'
26| ''
27| A←⎕
28| Q←25
29| →(3≠ρ,A)/ERROR
30| B[3;]←A
31| ''
32| 'PRESS TIME (MINUTES)'
33| ''
34| A←⎕
35| Q←32
36| →(3≠ρ,A)/ERROR
37| B[4;]←A
38| OUT←B
39| →0
40| ERROR:
41| ''
42| 'WRONG ANSWER, PLEASE TRY AGAIN'
43| ''
44| →Q
45| ⍝
46| ⍝ AN I/O FUNCTION FOR ESTABLISHING VALUES FOR
47| ⍝ THE DECISION VARIABLES.
48| ⍝
```

13. APPENDIX III - GRAPHICAL REPRESENTATIONS OF CONSTRAINT DATA USED IN MAXPRESS

Figure 1. Internal Bond vs. Press Time - Comparison of Panel Density

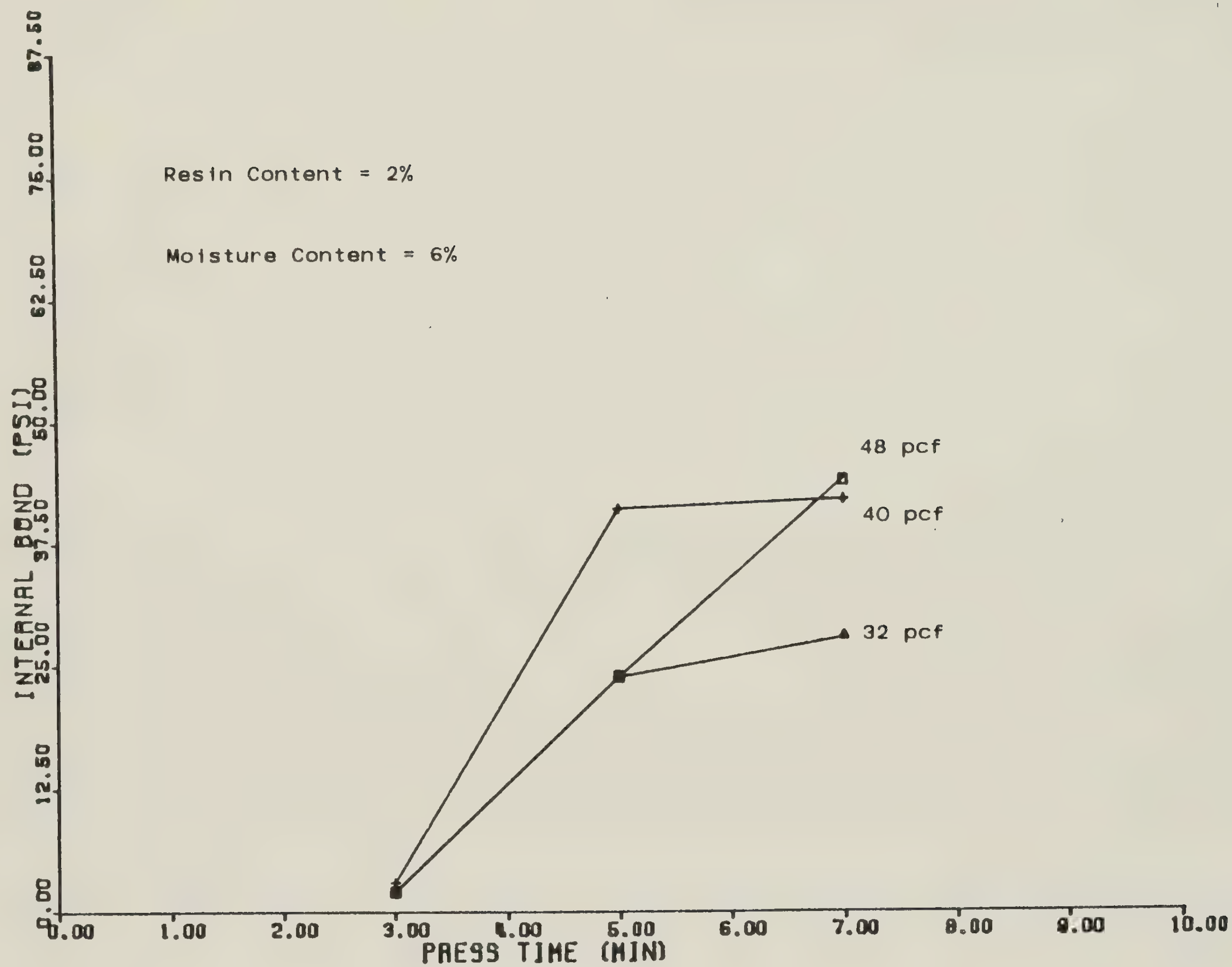


Figure 2. Internal Bond vs. Press Time - Comparison of Panel Density

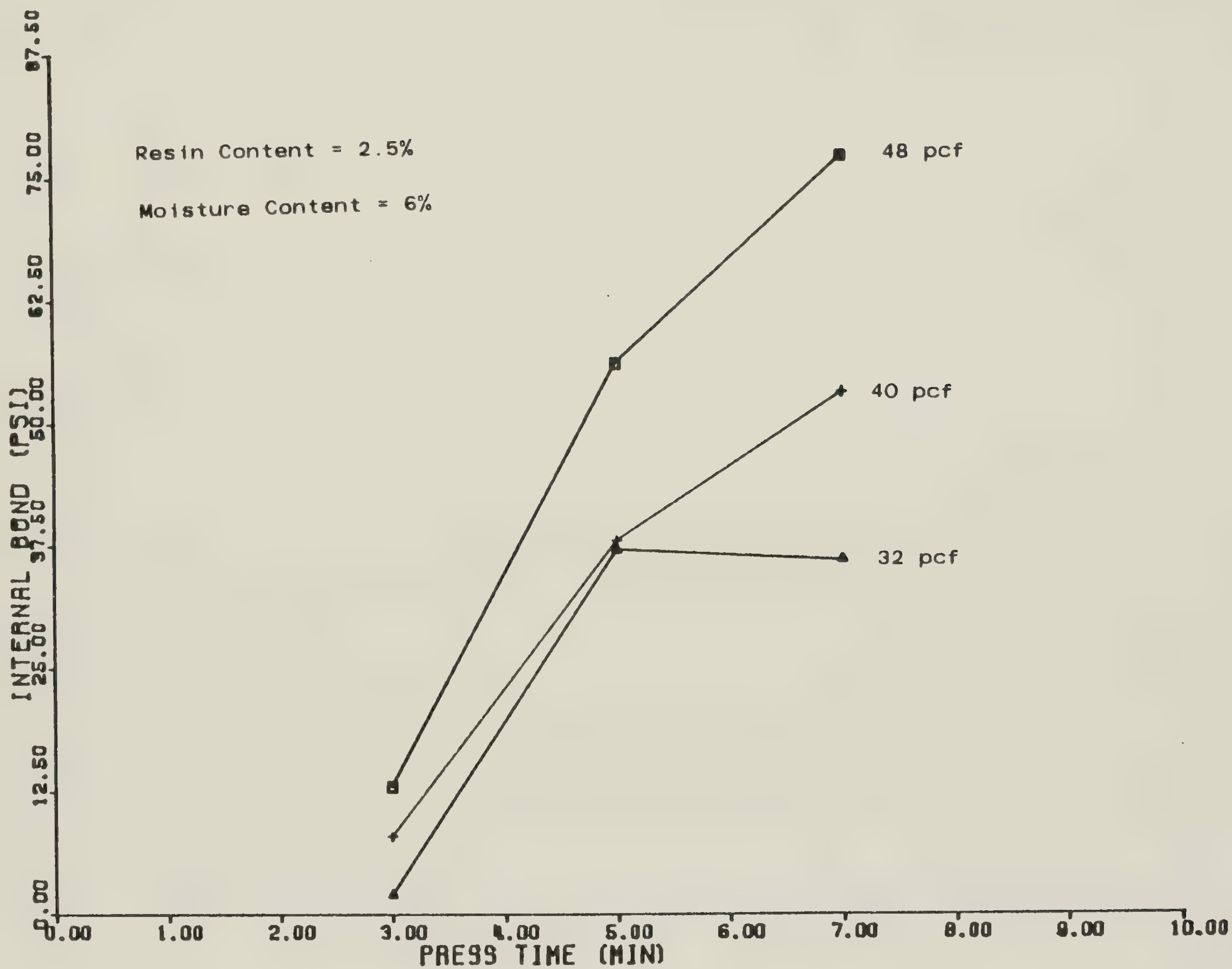


Figure 3. Internal Bond vs. Panel Density - Comparison of Press Time

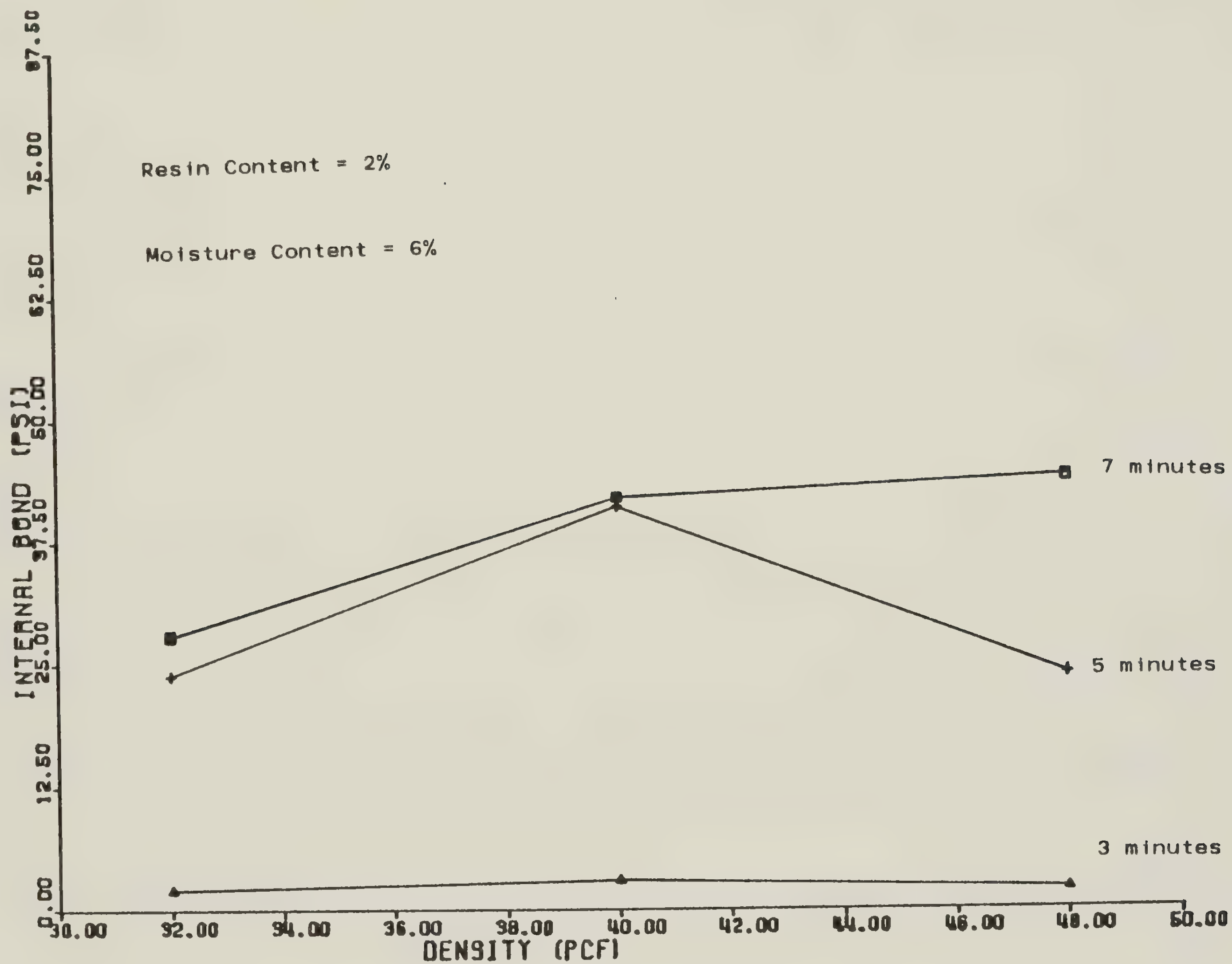
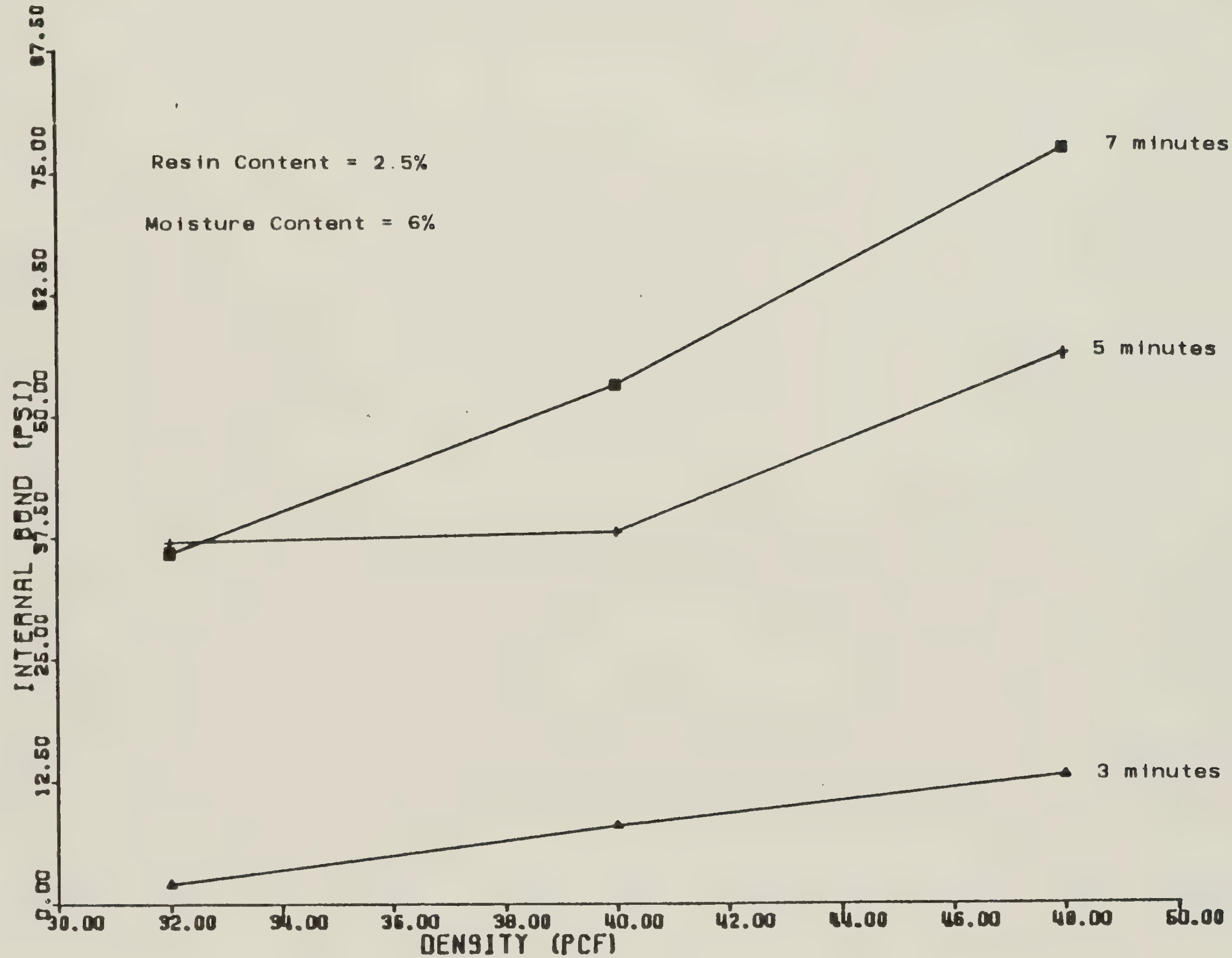


Figure 4. Internal Bond vs. Panel Density - Comparison of Press Time



14. APPENDIX IV - SAMPLE RUN OF MAXPRESS

```
**********************************************
**********************************************
**  WAFERBOARD PRODUCTION OPTIMIZATION MODEL **
**         ALBERTA RESEARCH COUNCIL          **
**       FOREST PRODUCTS PROGRAM: FP-19      **
**         AUTHOR: TOM I. GRABOWSKI          **
**       LAST REVISION: APRIL 29, 1982       **
**********************************************
**********************************************

*****WARNING: YOUR DATA FILE MUST BE COPIED INTO THIS WORKSPACE.

ENTER ONE OF THE FOLLOWING KEYWORDS:

EXPLAIN (GIVES A DESCRIPTION OF THE PROGRAM)

START (INITIATE RUNNING OF THE PROGRAM)

START

RUN DATE      1982 5 18 18

ENTER, IN ORDER, VALUES FOR THE FOLLOWING PARAMETERS:

PANEL THICKNESS (INCHES)

 : .4375

RESIN COST (DOLLARS/POUND)

 : .7

WAX COST (DOLLARS/POUND)

 : .07

WOOD COST (DOLLARS/O.D. POUND WAFERS)

 : .05

FUEL COST (DOLLARS/MCF NATURAL GAS)

 : 1.5

OTHER VARIABLE COSTS (DOLLARS/MSF)

 : 50

SELLING PRICE AT THE FACTORY GATE (DOLLARS/MSF)

 : 200
```

```
ENTER, FOR EACH PROCESS VARIABLE, THE FOLLOWING PARAMETERS:
MINIMUM POSSIBLE VALUE, MAXIMUM POSSIBLE VALUE, STEP SIZE:
***NOTE: STEP SIZE MUST EQUAL INTERVAL SIZE OF CONSTRAINT MATRIX.

EXAMPLE FOR MOISTURE CONTENT:

   6 8 .5

MOISTURE CONTENT OF THE PANEL (PERCENT)

 : 6 8 .5

RESIN CONTENT OF THE PANEL (PERCENT OF O.D. WEIGHT)

 : 2 2.5 .125

PANEL DENSITY (PCF)

 : 32 48 2

PRESS TIME (MINUTES)

 : 3 7 .5

STARTING POINT FOR VECTOR SEARCH;

ENTER, IN ORDER, VALUES FOR EACH PROCESS VARIABLE:

MOISTURE CONTENT (PERCENT)

 : 7

RESIN CONTENT (PERCENT)

 : 2.250

PANEL DENSITY (PCF)

 : 40

PRESS TIME (MINUTES)

 : 5

ENTER THE VALUE FOR LAMBDA

 : 150

ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 0

WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY? N
```

```
*****************************************************************************
                                                  M.C.     R.C.    DEN.      PRESS

STARTING POINT -  PROCESS VARIABLES:              7.000    2.250   40.000    5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                      14025.556
LAMBDA IS:                                                                 150.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                         5540.360
INTERNAL BOND (PSI) IS:                                                     56.568

INTERMEDIATE - PROCESS VARIABLES:                 7.000    2.375   38.000    4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                                 14758.844
VARIABLE PROFIT  (DOLLARS/SHIFT):                                         6878.821
INTERNAL BOND (PSI) IS:                                                     52.533

INTERMEDIATE - PROCESS VARIABLES:                 7.500    2.375   36.000    4.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                                 15071.017
VARIABLE PROFIT  (DOLLARS/SHIFT):                                         8910.858
INTERNAL BOND (PSI) IS:                                                     41.068

INTERMEDIATE - PROCESS VARIABLES:                 7.500    2.250   34.000    4.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                                 15086.437
VARIABLE PROFIT  (DOLLARS/SHIFT):                                        10150.026
INTERNAL BOND (PSI) IS:                                                     32.909

*****************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    150.000

                                                  M.C.     R.C.    DEN.      PRESS
FINAL POINT - PROCESS VARIABLES:                  7.500    2.250   34.000    4.000
FINAL VALUE OF LAGRANGE FUNCTION:                                        15086.437
VARIABLE PROFIT  (DOLLARS/SHIFT):                                        10150.026
INTERNAL BOND (PSI) IS:                                                     32.909
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES? N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH? N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA? Y
ENTER THE VALUE FOR LAMBDA

 : 160


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY? N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND? N

************************************************************************
                                            M.C.    R.C.   DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:        7.000   2.250  40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                             14591.236
LAMBDA IS:                                                        160.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                5540.360
INTERNAL BOND (PSI) IS:                                            56.568

INTERMEDIATE - PROCESS VARIABLES:           7.000   2.375  38.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                        15284.179
VARIABLE PROFIT  (DOLLARS/SHIFT):                                6878.821
INTERNAL BOND (PSI) IS:                                            52.533

INTERMEDIATE - PROCESS VARIABLES:           7.500   2.375  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                        15528.226
VARIABLE PROFIT  (DOLLARS/SHIFT):                                7920.762
INTERNAL BOND (PSI) IS:                                            47.547

INTERMEDIATE - PROCESS VARIABLES:           7.000   2.375  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                        15535.357
VARIABLE PROFIT  (DOLLARS/SHIFT):                                7810.251
INTERNAL BOND (PSI) IS:                                            48.282


************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    160.000

                                            M.C.    R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:            7.000   2.375  36.000   4.500
FINAL VALUE OF LAGRANGE FUNCTION:                               15535.357
VARIABLE PROFIT  (DOLLARS/SHIFT):                                7810.251
INTERNAL BOND (PSI) IS:                                            48.282
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES? N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH? N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA? Y
ENTER THE VALUE FOR LAMBDA

 : 155


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY? N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND? N

************************************************************************
                                            M.C.     R.C.   DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:        7.000    2.250  40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                               14308.396
LAMBDA IS:                                                          155.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  5540.360
INTERNAL BOND (PSI) IS:                                              56.568

INTERMEDIATE - PROCESS VARIABLES:           7.000    2.375  38.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                          15021.512
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  6878.821
INTERNAL BOND (PSI) IS:                                              52.533

INTERMEDIATE - PROCESS VARIABLES:           7.500    2.375  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                          15290.493
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  7920.762
INTERNAL BOND (PSI) IS:                                              47.547

INTERMEDIATE - PROCESS VARIABLES:           7.000    2.375  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                          15293.947
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  7810.251
INTERNAL BOND (PSI) IS:                                              48.282


************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    155.000

                                            M.C.     R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:            7.000    2.375  36.000   4.500
FINAL VALUE OF LAGRANGE FUNCTION:                                 15293.947
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  7810.251
INTERNAL BOND (PSI) IS:                                              48.282
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES? N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH? N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA? Y
ENTER THE VALUE FOR LAMBDA

 : 152.5


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY? N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND? N

**********************************************************************
                                           M.C.    R.C.   DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:       7.000   2.250  40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                             14166.976
LAMBDA IS:                                                        152.500
VARIABLE PROFIT  (DOLLARS/SHIFT):                                5540.360
INTERNAL BOND (PSI) IS:                                            56.568

INTERMEDIATE - PROCESS VARIABLES:          7.000   2.375  38.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                        14890.178
VARIABLE PROFIT  (DOLLARS/SHIFT):                                6878.821
INTERNAL BOND (PSI) IS:                                            52.533

INTERMEDIATE - PROCESS VARIABLES:          7.500   2.375  36.000   4.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                        15173.686
VARIABLE PROFIT  (DOLLARS/SHIFT):                                8910.858
INTERNAL BOND (PSI) IS:                                            41.068


**********************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    152.500

                                           M.C.    R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:           7.500   2.375  36.000   4.000
FINAL VALUE OF LAGRANGE FUNCTION:                               15173.686
VARIABLE PROFIT  (DOLLARS/SHIFT):                                8910.858
INTERNAL BOND (PSI) IS:                                            41.068

WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? Y
```

```
****************************************************************************
***********************       GAP SEARCH ROUTINE       ******************
****************************************************************************

ENTER, IN ORDER, VALUES FOR EACH PROCESS VARIABLE:

MOISTURE CONTENT (PERCENT)

 : 7.5

RESIN CONTENT (PERCENT)

 : 2.375

PANEL DENSITY (PCF)

 : 36

PRESS TIME (MINUTES)

 : 4

ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 42

ENTER THE VALUE FOR LAMBDA

 : 152.5

ENTER THE VALUE FOR PERTURBATION DEPTH (MAXIMUM IS THREE)

 : 1

****************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    152.500

                                             M.C.     R.C.    DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:             7.000    2.500   36.000   4.000
FINAL VALUE OF LAGRANGE FUNCTION:                                   2083.237
VARIABLE PROFIT  (DOLLARS/SHIFT):                                   8576.022
INTERNAL BOND (PSI) IS:                                               42.576
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES? Y
ENTER, IN ORDER, VALUES FOR THE FOLLOWING PARAMETERS:

PANEL THICKNESS (INCHES)

 : .4375

RESIN COST (DOLLARS/POUND)

 : 1.00

WAX COST (DOLLARS/POUND)

 : .07

WOOD COST (DOLLARS/O.D. POUND WAFERS)

 : .05

FUEL COST (DOLLARS/MCF NATURAL GAS)

 : 1.5

OTHER VARIABLE COSTS (DOLLARS/MSF)

 : 50

SELLING PRICE AT THE FACTORY GATE (DOLLARS/MSF)

 : 200


WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH? N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA? N
WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY? N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND? Y
ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 0
```

```
***************************************************************************
                                                M.C.    R.C.   DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:            7.000   2.250  40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                 12538.552
LAMBDA IS:                                                            152.500
VARIABLE PROFIT  (DOLLARS/SHIFT):                                    3911.936
INTERNAL BOND (PSI) IS:                                                56.568

INTERMEDIATE - PROCESS VARIABLES:               7.000   2.375  38.000   5.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                            13151.774
VARIABLE PROFIT  (DOLLARS/SHIFT):                                    4560.266
INTERNAL BOND (PSI) IS:                                                56.338

INTERMEDIATE - PROCESS VARIABLES:               7.000   2.375  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                            13456.744
VARIABLE PROFIT  (DOLLARS/SHIFT):                                    6093.753
INTERNAL BOND (PSI) IS:                                                48.282

INTERMEDIATE - PROCESS VARIABLES:               7.500   2.250  36.000   4.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                            13486.484
VARIABLE PROFIT  (DOLLARS/SHIFT):                                    6487.967
INTERNAL BOND (PSI) IS:                                                45.892

***************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    152.500

                                                M.C.    R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:                7.500   2.250  36.000   4.500
FINAL VALUE OF LAGRANGE FUNCTION:                                   13486.484
VARIABLE PROFIT  (DOLLARS/SHIFT):                                    6487.967
INTERNAL BOND (PSI) IS:                                                45.892

WOULD YOU LIKE TO CONTINUE THIS ANALYSIS? Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH? Y
```

```
*************************************************************************
************************        GAP SEARCH ROUTINE       ******************
*************************************************************************

ENTER, IN ORDER, VALUES FOR EACH PROCESS VARIABLE:

MOISTURE CONTENT (PERCENT)

 : 7.5

RESIN CONTENT (PERCENT)

 : 2.25

PANEL DENSITY (PCF)

 : 36

PRESS TIME (MINUTES)

 : 4.5


ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 42


ENTER THE VALUE FOR LAMBDA

 : 152.5


ENTER THE VALUE FOR PERTURBATION DEPTH (MAXIMUM IS 3)

 : 3


*************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    152.500

                                             M.C.    R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:             7.500   2.125  36.000   4.500
FINAL VALUE OF LAGRANGE FUNCTION:                                  295.674
VARIABLE PROFIT  (DOLLARS/SHIFT):                                 6762.934
INTERNAL BOND (PSI) IS:                                             42.408
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES?  Y
ENTER, IN ORDER, VALUES FOR THE FOLLOWING PARAMETERS:

PANEL THICKNESS (INCHES)

 : .4375

RESIN COST (DOLLARS/POUND)

 : 1.0

WAX COST (DOLLARS/POUND)

 : .07

WOOD COST (DOLLARS/O.D. POUND WAFERS)

 : .05

FUEL COST (DOLLARS/MCF NATURAL GAS)

 : 1.5

OTHER VARIABLE COSTS (DOLLARS/MSF)

 : 25

SELLING PRICE AT THE FACTORY GATE (DOLLARS/MSF)

 : 150


WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA?  Y
ENTER THE VALUE FOR LAMBDA

 : 90


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY?  N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND?  Y
ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 0
```

```
****************************************************************************
                                              M.C.    R.C.   DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:          7.000   2.250  40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                5316.654
LAMBDA IS:                                                           90.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                   225.536
INTERNAL BOND (PSI) IS:                                              56.568

INTERMEDIATE - PROCESS VARIABLES:             7.500   2.250  38.000   5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                           6180.475
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  1134.881
INTERNAL BOND (PSI) IS:                                              56.062

INTERMEDIATE - PROCESS VARIABLES:             7.500   2.250  36.000   6.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                           6659.785
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  1655.977
INTERNAL BOND (PSI) IS:                                              55.598


****************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =     90.000

                                              M.C.    R.C.   DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:              7.500   2.250  36.000   6.500
FINAL VALUE OF LAGRANGE FUNCTION:                                  6659.785
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  1655.977
INTERNAL BOND (PSI) IS:                                              55.598


WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES?  N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA?  Y
ENTER THE VALUE FOR LAMBDA

 : 87


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY?  N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND?  N
```

```
******************************************************************************
                                                M.C.     R.C.    DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:            7.000    2.250   40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                    5146.950
LAMBDA IS:                                                               87.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                       225.536
INTERNAL BOND (PSI) IS:                                                  56.568

INTERMEDIATE - PROCESS VARIABLES:               7.500    2.250   38.000   5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               6012.288
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      1134.881
INTERNAL BOND (PSI) IS:                                                  56.062

INTERMEDIATE - PROCESS VARIABLES:               7.500    2.250   34.000   5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               6551.262
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      2779.247
INTERNAL BOND (PSI) IS:                                                  43.356

INTERMEDIATE - PROCESS VARIABLES:               7.500    2.250   34.000   5.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               6647.408
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      3057.172
INTERNAL BOND (PSI) IS:                                                  41.267

INTERMEDIATE - PROCESS VARIABLES:               7.500    2.125   32.000   4.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               7107.088
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      5226.934
INTERNAL BOND (PSI) IS:                                                  21.611

INTERMEDIATE - PROCESS VARIABLES:               7.500    2.000   32.000   3.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               7505.767
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      7336.987
INTERNAL BOND (PSI) IS:                                                   1.940

INTERMEDIATE - PROCESS VARIABLES:               8.000    2.000   32.000   3.000
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                               7646.824
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      7490.224
INTERNAL BOND (PSI) IS:                                                   1.800


******************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    87.000

                                                M.C.     R.C.    DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:                8.000    2.000   32.000   3.000
FINAL VALUE OF LAGRANGE FUNCTION:                                      7646.824
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      7490.224
INTERNAL BOND (PSI) IS:                                                   1.800
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES?  N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA?  Y
ENTER THE VALUE FOR LAMBDA

 : 88


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY?  N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND?  N

**************************************************************************
                                              M.C.     R.C.    DEN.      PRESS

STARTING POINT -  PROCESS VARIABLES:          7.000    2.250   40.000    5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                   5203.518
LAMBDA IS:                                                              88.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                      225.536
INTERNAL BOND (PSI) IS:                                                 56.568

INTERMEDIATE - PROCESS VARIABLES:             7.500    2.250   38.000    5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                              6068.350
VARIABLE PROFIT  (DOLLARS/SHIFT):                                     1134.881
INTERNAL BOND (PSI) IS:                                                 56.062

INTERMEDIATE - PROCESS VARIABLES:             7.500    2.250   36.000    6.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                              6548.589
VARIABLE PROFIT  (DOLLARS/SHIFT):                                     1655.977
INTERNAL BOND (PSI) IS:                                                 55.598


**************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =    88.000

                                              M.C.     R.C.    DEN.      PRESS
FINAL POINT - PROCESS VARIABLES:              7.500    2.250   36.000    6.500
FINAL VALUE OF LAGRANGE FUNCTION:                                     6548.589
VARIABLE PROFIT  (DOLLARS/SHIFT):                                     1655.977
INTERNAL BOND (PSI) IS:                                                 55.598
```

```
WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VARIABLE COST FIGURES?  N
WOULD YOU LIKE TO CHANGE THE STARTING POINT FOR THE SEARCH?  N
WOULD YOU LIKE TO CHANGE THE VALUE OF LAMBDA?  Y
ENTER THE VALUE FOR LAMBDA

 : 87


WOULD YOU LIKE TO USE EXPLORATORY MOVES ONLY?  N
WOULD YOU LIKE TO CHANGE MINIMUM INTERNAL BOND?  Y
ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 42


*************************************************************************
                                            M.C.     R.C.    DEN.     PRESS

STARTING POINT -  PROCESS VARIABLES:        7.000    2.250   40.000   5.000
INITIAL VALUE OF LAGRANGE FUNCTION:                                5146.950
LAMBDA IS:                                                           87.000
VARIABLE PROFIT  (DOLLARS/SHIFT):                                   225.536
INTERNAL BOND (PSI) IS:                                              56.568

INTERMEDIATE - PROCESS VARIABLES:           7.500    2.250   38.000   5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                           6012.288
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  1134.881
INTERNAL BOND (PSI) IS:                                              56.062

INTERMEDIATE - PROCESS VARIABLES:           7.500    2.250   34.000   5.500
INTERMEDIATE VALUE OF LAGRANGE FUNCTION:                           6551.262
VARIABLE PROFIT  (DOLLARS/SHIFT):                                  2779.247
INTERNAL BOND (PSI) IS:                                              43.356

*************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =     87.000

                                            M.C.     R.C.    DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:            7.500    2.250   34.000   5.500
FINAL VALUE OF LAGRANGE FUNCTION:                                  6551.262
VARIABLE REVENUE (DOLLARS/SHIFT):                                  2779.247
INTERNAL BOND (PSI) IS:                                              43.356

WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  Y
WOULD YOU LIKE TO PERFORM A GAP SEARCH?  Y
```

```
**************************************************************************
**********************        GAP SEARCH ROUTINE        *****************
**************************************************************************

ENTER, IN ORDER, VALUES FOR EACH PROCESS VARIABLE:

MOISTURE CONTENT (PERCENT)

 : 7.5

RESIN CONTENT (PERCENT)

 : 2.25

PANEL DENSITY (PCF)

 : 36

PRESS TIME (MINUTES)

 : 6.5


ENTER VALUE FOR MINIMUM INTERNAL BOND

 : 42


ENTER THE VALUE FOR LAMBDA

 : 87


ENTER THE VALUE FOR PERTURBATION DEPTH (MAXIMUM IS THREE)

 : 3

**************************************************************************
OPTIMAL SOLUTION FOR LAMBDA =     87.000

                                          M.C.     R.C.    DEN.     PRESS
FINAL POINT - PROCESS VARIABLES:          6.500    2.250   34.000   5.000
FINAL VALUE OF LAGRANGE FUNCTION:                                6519.939
VARIABLE PROFIT  (DOLLARS/SHIFT):                                2855.678
INTERNAL BOND (PSI) IS:                                            42.118


WOULD YOU LIKE TO CONTINUE THIS ANALYSIS?  N
************************  END OF ANALYSIS  ***************************
```